A STUDY OF THE GERMINATION OF FRESHLY HARVESTED SEED OF SOME SORGHUM VARIETIES

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CHAPTER I

INTRODUCTION

Seeds of many plant species will not germinate for some time after they are ripe, even if they are placed under optimum conditions of moisture, light and temperature. They are in a dormant condition. Dormancy in small grains and some members of the grass family is a familiar phenomenon among seed technologists. The length of the dormant period varies from days to years, depending on species and variety. Dormancy is a powerful aid in the struggle for survival in species where a living plant would not survive a cold winter or a dry season. Some studies have indicated that sorghum (*Sorghum bicolor* (L.) Moench) seeds of some varieties show dormancy when freshly harvested.

Several different mechanisms are involved in dormancy. The seed coat may play an important role in germination, especially in permeability to water and oxygen for seed metabolism. Prechilling, hot water treatment, and scarification may break the dormancy of seeds.

Dormancy in seed usually does not persist long enough to delay normal planting time, but it could be a problem in an accelerated seed increase program. Also when two or more generations of plants are produced in a breeding program in a greenhouse or in a winter nursery, delay due to dormancy could be a problem. Therefore, information about dormancy will help breeders and researchers to harvest at the proper time and to store the seeds properly to avoid delay.

The purpose of this work was to study the germination of sorghum seeds of varying degrees of maturity and to determine the age of sorghum seeds when dormancy occurs.

CHAPTER II

LITERATURE REVIEW

Grain sorghum is one of the important crops in the world. It is cultivated throughout Africa and extensively in India, China, Manchuria and the United States. For the period 1934 - 1938, approximately 90 percent of the total world crop was grown in China, India, Manchuria, and French West Africa. About 75 percent of that total was used as human food in the form of bread, porridge, confectionaries, and 16 percent was used as livestock feed. Some quantities are used for making an alcoholic drink similar to beer (40).

Sorghum is an important crop in the United States particularly in the southwest where the rainfall is insufficient for the production of corn. In 1967, of the sorghum that was grown in the United States, approximately 81 percent was harvested for grain, 13 percent for forage, 5 percent for silage, and about 1 percent for broomcorn and syrup (36).

Dormancy in grain sorghum has been recognized for some time. It has been defined as an internal condition of the chemistry or stage of development of a viable seed that prevents its germination although an optimum environment for growth is provided (63). Wareing (65) discussed two main theories regarding the mechanism of dormancy in plants. One theory proposed by Vigis (64) emphasized the importance of the seed covering, such as testa, endoderm, and pericarp, on dormancy. These layers restrict gaseous exchange especially oxygen uptake, and lead to partial anaerobiosis especially at higher temperatures. The theory explained that freshly-harvested seeds of cereals will germinate at low temperature (10° C), but will not germinate at higher temperatures. However, after a period of after-ripening in dry storage, seeds of cereals gradually become capable of germinating over a wider range of temperatures. It was held that such prolonged anaerobiosis may throw the meristematic tissues into a dormant state, so that they may remain dormant even when the interfering coverings are removed. The other theory stresses the possible hormonal regulation of dormancy (65). Growth hormones appear to play a profound role in the regulation of other aspects of plant development. It is possible that dormancy is controlled by a hormone also. Therefore, growth may be prevented either by the absence of some growth promoting substance, or by the presence of an actively inhibiting substance.

Seed size of sorghum grain does not appear to be a varietal factor in germination from the standpoint of reserve food supply as small-seeded sorghums show a tendency to germinate better than the large-seeded varieties (60).

Types and Theories of Dormancy

Two <u>types</u> of dormancy have been observed in sorghum. One type is referred to as post-harvest or natural dormancy and the other is induced dormancy (53). Post-harvest dormancy sometimes occurs with freshly-harvested seed. It is characterized by failure of freshly-harvested sorghum seed to germinate when placed under optimum conditions for germination. It usually does not persist for a long enough period after harvest to interfere with planting time, except in an accelerated seed-increase program. Induced dormancy refers to dromancy which persists in a sorghum seed long after the natural post-harvest dormancy has been removed by after-ripening. Both types of dormancy are similar in characteristics and mechanisms, but they can be distinguished by the above definitions.

In regard to the <u>theory</u> of dormancy, Vigis (64) reported that the transition from the state of full growth activity to true dormancy occurs gradually. The first phase of the rest period is called early rest or predormancy. The organs are still able to grow in this state, but only in a narrower range of external conditions than at the time of full growth activity. Proper external factors are essential for the continuation of growth during this phase. The transition from predormancy to true dormancy marks the entrance to the middle phase of the rest period, which is the main rest. At this stage the depression of growth activity is strongest and dormancy is at the deepest level. Truly dormant shoot apices and seed embryos cannot be induced to immediate normal growth. The phase of main rest passes on to the final phase of the rest period, which is called after-rest for buds and the period of after-ripening for seeds. The internal condition of dormant organs, after the completion of true dormancy until the state of maximum growth activity is attained is called post-dormancy. During this phase of the rest period, the organs are in the state of relative or conditional dormancy, and they are able to start their growth within limits of certain external conditions. After the after-rest and the rest period are terminated and post-dormancy disappears, the limits of external conditions are widest.

In dormant seeds the growth mechanism is switched off although other metabolic processes such as respiration are functioning. Black (5) noted, as reported by Roberts and his co-workers, that respiration of dormant barley seed is characterized by a lower participation of the pentose phosphate pathway than in non-dormant seeds. Protein synthesis occurs in dormant seeds but the rate does not differ much from non-dormant seeds. There is a significantly higher rate of RNA synthesis in dormant seeds.

In order to better understand the processes that might be responsible for dormancy, it seems necessary to better understand the processes that take place within the seed during germination in response to the variations that take place outside the seed. To this end, the literature on Factors Affecting Germination will be reviewed under four major headings: (a) Seed coats, (b) Immature embryos, (c) Temperature, moisture, light, and inhibitors, and (d) Storage conditions and weather. Further, the literature concerning Seed coats will be subdivided into mechanical resistance to germination, restriction of gas exchange, and restriction of the entry of water.

Factors Affecting Germination

Factors affecting germination are: (a) seed coat, chiefly the effect on permeability, (b) inhibitors, such as coumarin, NH_3, and HCN, (c) promoters, such as, nitrates and gibberellin, (d) light and dark, (e) temperature, and (f) moisture, chiefly the effect on seed metabolism (62).

Whitcomb (66) reported that the dormancy of cereals might be affected by the following factors: (a) stage of maturity at time of harvest, (b) period of curing in the field after harvesting previous to threshing, (c) variation of temperature of the germinators in the laboratory, (d) aging of seed in the laboratory and (e) germinating in the field.

Seed Coat

The seed coat of sorghum consists of the fused pericarp and testa. The pericarp is the original ovary wall. When it is at maturity, it has about the same number of cells as at fertilization. The cells have become much larger, and wall thickening has occurred. Doggett (22) noted that the pericarp consists of (a) the epidermis, a layer of thick-walled cells covered with a cuticle of uneven thickness, (b) the cells of the hypodermis with thick walls, arranged in one to three layers, (c) the mesocarp consisting of large, thin-walled, elongated cells, (d) cross cells, and (e) tube cells. The testa, located between pericarp and endosperm and consisting of thick-walled pigment-containing cells, represents the inner layer of the inner integument. If present, it is usually thick, with thin outer and radial walls and much swollen inner walls. Many varieties of sorghum do not have the testa.

Swanson (59) reported that pigmentation may occur (a) in the epidermal and hypodermal cells of the pericarp, (b) in the testa, or (c) in both regions. Three factors (Bb, Rr, and Ss) are responsible for the inheritance of color in the kernels of sorghum. Factor B is assumed to be responsible for the development of the nucellar layer and its associated pigment. Its recessive allelomorph, b, determines the absence of a nucellar layer and a consequent lack of any color due to nucellar pigmentation. The B factor may cause a slight coloration in the epidermis of the pericarp when in combination with the factor S. S is assumed to be a factor determining the development of a vestigial type of mesocarp, while its recessive allelomorph, s, determines a well-developed, starchy, opaque mesocarp. A thick starchy mesocarp masks nucellar color and inhibits even a slight expression of color in the pericarp due to B. R is a factor determining coloration in the epidemal and hypodermal cells of the pericarp, r being the allelomorph responsible for the absence of color in the pericarp. R is greatly intensified in the presence of B and S. Slight coloration in the pericarp due to the nucellar factor, B, is independent in its inheritance from the pericarp color factor, R, however, the interaction of these two factors produces a more intensive color in the presence of S. Brown kernels usually contain tannin and related compounds, while white kernels do not.

Clark, Collier and Langston (15) found morphological differences in the seed coats of dormant and non-dormant sorghum varieites. They also found that seed with a brown testa and pericarp were more dormant than those with a white seed coat. The pericarp of each variety was different in thickness. Therefore, it is possible that the pericarp thickness could be responsible for the different levels of dormancy in different varieties of sorghum.

Mechanical resistance to germination can be due to restriction of expansion imposed by seed structures. Crocker and Davis (19) reported that dormancy of Alisma plantago was due to the mechanical restraint of the seed coat. The restraint enables the seed to be in water for years without germination. Copper sulfate induced a deeper dormancy, possibly by increasing the hardness of the seed coats. Acids and bases caused a weakening of the seed coat and made the imbibition and osmotic swelling of the embryo break away the coat cap at the large end of the embryo.

Ives (33) reported that the pericarp of *Ilex opaca* prevented the elongation of the embryo once it had developed from an immature state following seed fall. Steinbauer (58) suggested that elongation of the embryo of *Franxinus* is restricted by mechanical resistance of the enveloping endosperm tissue and surrounding suberized membranes.

Restriction of gas exchange reduces germination. The oxygen requirement of each species and variety depends on the permeability of the seed coats and underlying tissues to oxygen and carbon dioxide. Atwood (1) concluded that the delay in germination is occasioned by restriction in the supply of oxygen, which thus acts as a limiting factor to germination. The seed coat is probably an obstruction to oxygen entry. Morinaga (43) concluded that seeds of cat-tail (*Typha latifolia* L.) which germinated poorly or not at all in air, germinated promptly when the oxygen concentration of the air was reduced by diluting with hydrogen or nitrogen. Favorable concentrations were obtained by diluting the air with 40 to 80 percent (by volume) of hydrogen or nitrogen, and approximately 96 percent germination was obtained. Crocker (18) concluded that delayed germination in the upper seed of cocklebur is caused by the seed coat excluding oxygen, while in *Axyris amaranthoides*, *Abutilon avicennae*, and many other seeds it is secured by the coats excluding water. Kidd and West (35) stated that the seed coats of *Brassica alba* played a significant role in gaseous exchange of the embryo during the early stage of seed maturity, but following maturity the seed coats gradually lost their power of restricting gas exchange along with the loss of vital activity of their cells. Apparently the living testa from green seed behaves in relation to its thickness in the same manner as a thin film of water and not only restricts the entry of oxygen but also respires a portion of that free to diffuse into the embryo. Atwood (1) reported that delayed germination of *Avena fatua* was due to a restriction by the seed coat in the supply of oxygen reaching the embryo, because of the impermeability of the testa. Wright and Kinch (67) reported that dormant sorghum seeds respire less than non-dormant seeds. Since dormant sorghum seeds absorb less oxygen than non-dormant seed, it is believed that the seed coats restrict the passage of oxygen to the embryo.

Restriction of the entry of water to the embryo by the seed coat may interfere with germination, also. Crocker (18) reported that the seed coats of *Axyris amaranthoides*, *Abutilon avicennae*, *Chenopodium album*, *Iris sibirica* and *Iris pseudacorus* restricted the entry of water. He also reported that if a cap of endosperm of *Iris sibirica* was removed, immediate germination occurred.

Roberts (47) concluded that the rate of water absroption of rice was the same in dormant and non-dormant seeds and that dormant seeds were capable of absorption sufficient water for germination. The covering structures, therefore, do not cause dormancy by restricting the entry of water. He (48) also reported that when dormant rice seeds were soaked in water, they attained a moisture content close to 30 percent. Pre-soaking seeds to achieve moisture contents in this region can stimulate the breaking of dormancy.

Rost (52) reported that crushing the seed coat of the yellow foxtail grass during embryo formation and the movement of water across the coat when the caryopsis is mature, could account for the release and transport of soluble material within the coat into the embryo and aleurone layer. The disruption of the enclosing coat either mechanically or by chemical breakdown would permit leaching of the inhibitor and the subsequent loss of dormancy. Wright and Kinch (67) stated that mechanical scarification of sorghum seed effectively broke dormancy, and there was no evidence of water soluble inhibitors in the glumes or various layers of the seed coat being involved in dormancy.

Immature Embryo

Dormancy due to immaturity of the embryo is common in the grass family and some other families. It might be due to the absence of an adequate food supply to the embryo. Larson, Harvey, and Larson (39) concluded that the length of the rest period of common varieties of wheat, oats, barley, and rye at soft dough, hard dough, and ripe stages indicated that the longest rest period was in immature seeds. The length of the rest period varied greatly with the variety and storage condition. Robertson and Curtis (49) reported that immature kernels of five winter wheat varieties were collected at 3-day intervals from 15 days after anthesis until they were ripe, about 39 days after anthesis. Air-dried kernels (dried 3 days) germinated better than fresh kernels in the more immature stages. Harlan and Pope (29) reported that immature barley seeds, after 6 days of pollination, germinated less than the mature seed. Coffman and Stanton (16) stated that freshly harvested seeds of some varieties of oats contained considerable moisture and did not germinate as rapid as seed that was allowed to dry for 3 or 4 days. However, many of the varieties continued to germinate slowly after the seed was air-dry.

Sprague (56) reported that immature kernels of corn having a similar moisture content to mature kernels germinated poorly. The percentage of germination increased rather steadily with increasing maturity and decreasing moisture content of the sample. A high moisture content appears to be associated with a high degree of variability in the time required for germination. Frey, Ruan, and Wiggans (25) concluded that germination of oat seeds increased with maturity up to 20 to 28 days after anthesis. A few seeds germinated when harvested as early as 4 to 6 days after anthesis.

Gritton and Atkins (28) reported that the development of dormancy of sorghum seed seems to be associated with the final stages in the maturation process. The mechanism or constituents which affect seed dormancy may be developed sometime during the interval from termination of meristematic activity in the embryo to final maturation of the seed. Robbins and Porter (50) concluded that freshly harvested, immature seeds of sorghum were dormant. Dormancy was overcome by curing, by prechilling, and by continuing at 20 to 30° C until all variable seed had germinated. Kersting, Pauli, and Stickler (34) reported that Combine Kafir-60 seeds harvested 9 days after pollination failed to germinate but 12-day or more seed germinated.

Temperature, Moisture, Light and Inhibitors

The optimum temperature requirement for germination of cereals and other seeds is different. It depends on species and growth habit of the species. Actually, seeds of most species germinate better in warm temperatures. Chaudhary and Ghildyal (12) reported that the temperature range of 26.5 to 37.5^{o} C appeared to be favorable for germination of rice seeds. The rate and the percentage of germination were markedly reduced at 10^{o} C. The germination of seeds was practically inhibited at the constant temperatures of 41 or 7^{o} C, but the alternation from inhibitive high temperature (41^{o} C) to 24^{o} C or to inhibitive low temperature (7^{o} C) promoted germination. Some products of metabolism may accumulate in the embryo at high temperature and inhibit germination. With alternating temperatures, a favorable metabolic balance is created which promotes germination.

Rosenow, Casady and Heyne (51) reported that freezing damage to immature sorghum seed is apparently proportional to the moisture content of the embryo. The plumule seems to be the first organ injured by freezing. Freezing temperatures as low as 22^{o} F generally did not reduce germination in sorghum seed of 25 percent moisture or less. Pinthus and Rosenblum (45) stated that the minimum temperature required for germination of sorghum seed is between 8 and 10^{o} C. The hybrid RS 610 was superior to the varieties D.D. Yellow Sooner and Martin in germination at low temperatures.

Moisture, as an influence on seed germination, is known as an external factor, which can also influence dormancy. Seeds with higher moisture have a tendency to lose dormancy more rapidly than those with low moisture. Collier (17) reported that the moisture percentage decreases during the first 14 to 16 days after bloomings were caused by dry matter accumulations exceeding water accumulations in the young caryopses. Actual water losses from caryopses usually did not occur until 16 to 22 days after blooming, or when moisture percentages were below 50 percent. Then, decreases were linear for some varieties and hybrids. Evans and Stickler (24) stated that germination of some sorghum varieties progressively decreased with increasing moisture tension. Greater time was required to reach final germination as osmotic tension increased indicating that the length of time required for germination under drought stress would be particularly critical under field conditions.

Carlson and Atkins (9) indicated that sorghum grain of some varieties containing 10 to 20 percent moisture was not reduced in viability by freezing treatments, while grain of 30 to 45 percent moisture content generally was reduced in germinability. Gritton and Atkins (28) suggested that moisture content of the sorghum grain was a prime factor in determining the extent of reduction in viability from freezing temperatures. Sorghum grain with 15 percent moisture was not reduced appreciably in germinability by freezing, but grain with 25 to 45 percent moisture was. Generally, as the grain increased in moisture content and as the temperature was lower, the duration of exposure necessary for reducing seed viability was decreased. Clark, Collier and Langston (14) found that seeds of Feterita 18 days or more after anthesis germinated 100 percent after they were dried to approximately 12 percent moisture. They also found that there was little difference in germination response of seeds of Combine Kafir-60 and Feterita when the seeds were germinated immediately after harvest without drying.

Among cultivated plants, there is very little evidence for <u>light</u>

as a factor influencing germination. The seeds of most cultivated plants usually germinate almost equally well in the dark and in the light (41). Toole, et. al. (61) reported that the photoreaction possibly is present in all seeds, but it is not obligatory for the germination of all seeds. The photoreaction controls the level of compounds necessary in the germination process, but the levels of these compounds are also controlled by other reactions that are under the influence of temperature, nitrate and other factors.

The possible locations of the inhibitory substances responsible for seed dormancy are the seed coat, the embryo, and the endosperm. Each species may have a similar or different inhibitory substance at the same or different location. Barton and Solt (3) reported that mature wheat endosperm contained a water-soluble substance inhibitory to the action of human salivary amylase (preventing starch degradation) on native wheat starch granules. The inhibitor is absent in immature wheat kernels and appears at about the time the seed attains its mature shape. Elliot and Leopold (23) stated that the seed hull of barley contained the largest amount of inhibitor (a polypeptide of unsaturated lactones) although some is present in both the endosperm and embryo. The inhibitor is more sensitive to alpha-amylase than beta-amylase. Goodsell (27) reported that the dormancy of sorghum seed was due to the presence of some inhibitory substances present in the seed coat. Hot water treatment either dissolved or altered the inhibitory substance so that it no longer retarded germination.

Storage Condition and Weather

Storage condition influences seed germination of cultivated plants. Some species need resting time or a period of water loss to overcome dormancy. The temperature during storage also influences seed germination. Canode (7) found that normal seeds of timothy and tall oatgrass retained essentially the same germination for 5 years regardless of the storage condition. He also found that normal seeds of orchardgrass and normal meadow foxtail seeds were not reduced in germination by warm storage but were lowered by cool storage associated with high humidity. He (8) concluded that the length of time the grass may be stored without serious reduction in germination depended on the species, kind of storage, and condition of the seed when placed in storage. Whitcomb (66) found that cereal grains had a dormant period following harvest. Aging in the laboratory was effective in decreasing dormancy. Wright and Kinch (67) suggested that grain sorghum seed containing more than 37.5 percent moisture would not readily germinate until the seed had been dried. They indicated that storage of the seed in the laboratory reduced moisture content of the sorghum seed and increased the germination percentage. Nutile and Woodstock (44) reported that sorghum seed, through an after-ripening period in dry storage, gradually becomes less specific in its temperature requirements for germination. Freshly harvested seed may show some dormancy at 77 to 80° F and increasing dormancy at 68 to 60° F. The storage time required for complete germination at these temperatures is progressively greater as the germination temperature is lowered. Brown, et. al. (6) found that dormancy is less common in sorghum than in barley or oats and it disappeared after 2 months storage at 104° F.

The phenomenon of seed dormancy may be due to weather conditions or there may be other inhibiting factors related to or independent of weather. Chang (11) reported that weather is the cause of long or short periods of dormancy in small grains, and that dry storage produced the longer dormant periods. He explained that small grains of the 1939 crop were placed in dry storage, whereas, those of the 1938 crop were left in fields and subjected to rainfall and applications of water sprays. The 1939 crop had longer rest periods than the same kinds and varieties of seeds of the 1938 crop. On the other hand, Ghosh (26) reported that dry and sunny weather during grain development and ripening of rice resulted in shorter post-harvest dormancy than moist and cool weather. Roberts (46) reported that harvesting rice seed prematurely tends to speed up the processes leading to loss of dormancy whereas late harvesting has little influence on the date on which the mean dormancy period is achieved. Casey (10) found that a prolonged rest period of sorghum grain was a result of dry weather that prevailed from early summer until late fall. He also found that sorghum crops grown under normal rainfall conditions produced seed which had a short period of dormancy.

Breaking Seed Dormancy

Methods of breaking seed dormancy have been suggested. Morinaga (42) concluded that (a) alternate temperatures were effective in germination of seeds of *Cynodon dactylon*, (b) light and nitrate were effective in the germination of *Cynodon* seeds, when applied together with alternating temperatures, and (c) mechanical treatment with concentrated sulfuric acid was effective in forcing the germination of *Cynodon* and *Typha* seeds at constant temperatures.

Heit (30) found that dormant stocks of wheat, barley, and rye when treated at 15^{o} C constant temperature, yielded rapid and complete germination in about one week. It was more efficient as it saved a prechilling or drying period. Bartel (2) found no increase in the percentage of germination of green wheat seeds that were treated with 0.5 and 1.0 percent of thiourea or with high and low temperatures.

Delouche and Nguyen (21) found that soaking rice seed in water, 0.1 percent ethylene chlorohydrin, and 0.25 percent sodium hydrochlorite at 40^{o} C for 24 to 72 hours effectively promoted germination of dormant seed. They also found that the ethylene chlorohydrin treatment was the most effective.

The differences in compactness of the seed coats of johnsongrass and sudangrass caryopses blocked the expanding embryos (32). Removal of the scales from johnsongrass caryopses greatly increased the germination percentage (31). Evans and Stickler (24) reported that, at o-atmosphere tension, gibberellic acid increased the germination of sorghum grain the first day, but had no significant effect thereafter. They also found that at 15 atm, gibberellic acid increased the extent of germination each day. Wright and Kinch (67) found that dormant seeds of grain sorghum that were soaked in 1.0, 0.4, 0.2, and 0.1 percent of potassium nitrate solution for 24 hours, gave essentially complete germination. They also found that dormant seed exposed to alternating 30 to 40^{o} C temperature gave a higher germination than the check. Stanway (57) found that an alternating temperature of 20 to 30^{o} C was more favorable for maximum germination of sorghum seed than 20 to 30^{o} C alternating temperature following prechilling treatment. He also found that freshly harvested mature seed did not need a prechilling treatment. Thornton (62) reported that removal of the pericarp layer in dormant seed of grain sorghum did not break dormancy. When the remaining integumentary layer was pierced germination was initiated.

Black (5) concluded that general methods for breaking seed dormancy are: (a) chilling at 0-5^{o} C for several days, (b) exposing to the light, and (c) application of chemical compounds, such as gibberellic acid, malonate, fluoride, iodoactate, nitrate and nitrite ions.

Physiology of Germination

Seed coats, moisture content, temperatures, concentration of oxygen and carbon dioxide, light, embryo versus endosperm respiration, age of seeds, dormancy, fungi, bacteria, composition of the seed, and respiration enzymes are factors affecting respiration of seeds (20).

Germination is an energy requiring process. It depends on the respiration of the seed. It is possible that oxygen exerts its stimulative effect on germination by increasing respiration which yields more energy (54). Generally, a rise in temperature causes an increase in the rate of respiration in seeds. Temperature can only affect respiration when oxygen freely diffuses to the respiring tissue. If oxygen diffusion is limited, an increase in temperature will have little effect. An increase in the oxygen tension can also increase the rate of respiration of seeds (41). Siegel and Rosen (55) concluded that celosia, rice, and cucumber germinated under anaerobic condition. Lettuce seeds, which germinated in 2 percent but not 1 percent of oxygen, were not benefitted by ATP when incubated without oxygen.

Ching and Schoolcraft (13) reported that loss of viability and vigor of crimson clover and perennial ryegrass seeds was not due to depletion of food but was related to the metabolic activity. Koller et al (38) reported that lipids, carbohydrates, nitrogen, nucleic acid metabolism, and oxidative processes were involved in seed germination. Kneen (37) stated that germination of mature sorghum seeds led to increase in alpha-amylase activity. The amylase system of sorghum malt was composed primarily of alpha-amylase accompanied by relatively small quantities of beta-amylase.

Belderok (4) reported a schematic pathway leading from dormancy to normal germination and growth of cereal seed. For after-ripening of seed to occur an increase of the oxygen to permeable layers of the seed coat was necessary. Oxygen produces a synthesis of hydrolytic enzymes and a production of sugar, amino acid, and some other compounds in the endosperm. It also yields a formation or release of gibberellin in the embryo. If gibberellins are low, the release of glutathione and cystein will occur in the embryo. If gibberellins are high, the synthesis of hydrolytic enzymes will occur in the endosperm. Then growth occurs and germination follows.

CHAPTER III

MATERIALS AND METHODS

Four sorghum varieties, OK632, BOK94, ROKY8 and Sumac 1712 sorgo were planted at the Perkins Agronomy Research Station in 1972. The experimental procedure was as follows:

1. Bagged 70 heads at random in each variety, just before the heads began to bloom, and marked 70 additional heads in a similar stage of development. OK632, BOK94, and ROKY8 heads were bagged and marked on August 4, 1972, while Sumac 1712 heads were bagged and marked on August 11, 1972 because of later maturity.

2. Harvested 10 each of the bagged and open (marked) heads of each variety at 3, 4, 5, 6, 7, and 8 weeks after bagging.

3. Selected nine bagged heads of each variety and divided them into three lots of three heads each to form three replications for germination studies. Each replication was later assigned to one of three similar Stults germination chambers.

4. Followed the same procedure for open heads of each variety.

5. Threshed each lot, counted 50 seeds each, treated seeds with captan, and placed the seeds immediately in 3 x 3 x 1 inch plastic germination boxes with covers after adding 1 ml of water to the 3 x 3 inch Kimpax paper substrate. The germination was set for alternating temperature of 20 and 30^{o} C during a 16 hour dark and an 8 hour light period.

6. Then divided each lot of seeds into two sub-lots, putting one sub-lot of each variety in cold storage (5^{o} C) and putting the other sub-lot in the laboratory at room temperature (20^{o} C).

7. Germinated each sub-lot each week for 7 weeks.

8. Counted germinations at 4 and 10 days and used the total of the two counts as the germination percentage.

For purposes of discussion, the word dormancy will be used to indicate a reduced germination whether due to immaturity when harvested or subsequent treatments.

The data analyzed were means of the three replications since occasional observations were missing. The five-factor interaction mean square was used as experimental error. Unless otherwise indicated the initial germination (zero storage week) was not included in the analysis because it did not combine with the comparative factors. In Figure 13 through 20 data from the initial germinations (zero storage week) have been included as points of reference.

CHAPTER IV

RESULTS AND DISCUSSION

The data collected from the germination study were analyzed as a factorial experiment and the analysis of variance is shown in Table I. There was a highly significant difference among the varieties. The average germination percentage over all conditions was 60.6 for Sumac 1712, 59.2 for OK632, 53.7 for BOK94, and 45.9 for ROKY8 (Table II). Sumac 1712 has brown seed, OK632 was an F_1 hybrid, BOK94 has bright weather resistant grain, and ROKY8 has yellow endosperm. Yellow endosperm varieties are often lower in germination than varieties with normal endosperm.

There was a highly significant difference between the average germination percentage of bagged heads and open heads (Table I). The average germination percentage over all varieties and conditions was 61.9 for open heads and 47.8 for bagged heads (Table III). Seeds from open heads usually germinate better than seeds from bagged heads unless the open heads are severely weathered. Open heads have more light and air movement, and less moisture, mold, and insects.

The interaction of varieties times bagged-open heads was highly significant (Table I). Seeds of the open heads of each individual variety germinated better than the seeds from bagged heads of the same variety as shown in Table III. The highest average germination percentage for open heads was 65.8 for OK632, while the lowest average

TABLE I

ANALYSIS OF VARIANCE

Source	d.f.	MS	F-value
Variety (V)	3	7456.6	159.39**
Bagged-open (B-O)	1	33711.9	720.59**
V x B-O	3	1420.5	30.36**
Cold-warm (C-W)	1	17935.2	383.37**
V x C-W	3	140.5	3.00*
B-O x C-W	1	206.3	4.41*
V x B-O x C-W	3	202.4	4.33*
Collection week (CW)	5	16127.9	344.73**
V x CW	15	1230.8	26.31**
B-O x CW	5	1137.5	24.31**
V x B-O x CW	15	483.3	10.33**
C-W x CW	5	5469.4	116.91**
V x C-W x CW	15	470.6	10.06**
B-O x C-W x CW	5	45.3	0.97
Storage week (SW)	6	190.3	4.07**
V x SW	18	83.3	1.78**
B-O x SW	6	50.0	1.07
V x B-O x SW	18	60.9	1.30
C-W x SW	6	331.3	7.08**
V x C-W x SW	18	41.5	0.89
B-O x C-W x SW	6	48.9	1.05

TABLE I (CONTINUED)

Source	d.f.	MS	F-value
V x B-O x C-W x SW	18	59.5	1.27
CW x SW	30	321.8	6.88**
V x CW x SW	90	145.4	3.11**
B-O x CW x SW	30	72.4	1.55
V x B-O x CW x SW	90	60.0	1.28
C-W x CW x SW	30	117.4	2.51**
V x C-W x CW x SW	90	64.6	1.38
B-O x C-W x CW x SW	30	43.9	0.94
V x B-O x C-W x CW x SW	90	46.9	
Corrected total	691	418.3	

*significance at 0.05 level.

**significance at 0.01 level.

TABLE II

AVERAGE GERMINATION PERCENTAGE OF SEEDS FROM FOUR VARIETIES

Variety	Germination percentage
ROKY8	45.9
BOK94	53.7
OK632	59.2
SUMAC 1712	60.6

TABLE III

AVERAGE GERMINATION PERCENTAGE OF SEEDS FROM BAGGED AND OPEN HEADS FROM FOUR VARIETIES

Variety	Bagged or open	Germination percentage	Difference
ROKY8	Bagged	39.1	13.6
	Open	52.7	
BOK94	Bagged	42.7	21.9
	Open	64.6	
OK632	Bagged	52.6	13.2
	Open	65.8	
SUMAC 1712	Bagged	56.7	7.8
	Open	64.5	
Average	Bagged	47.8	14.1
	Open	61.9	

was 52.7 for ROKY8. Sumac 1712 and BOK94 were very similar to OK632. Seed from bagged heads of Sumac 1712 had the highest average germination percentage of 56.7, while ROKY8 again had the lowest germination of 39.1. These data are presented graphically in Figure 1. The largest and smallest differences in germination percentage between bagged and open heads came from BOK94 and Sumac 1712, respectively. Since the interaction of varieties times bagged-open heads was highly significant, this indicated that the varieties responded differently to bagging or lack of it. But the interaction was not very evident in Figure 1.

There was a highly significant difference between cold and warm storage conditions as shown in Table I. The average germination percentage in warm storage was 60.0, while in cold storage it was 49.7 (see Table IV). The average germination percentage in warm storage was higher than in cold storage perhaps because the warm storage condition permitted some maturation of the seeds, especially from the two earlier collection weeks. On the other hand, cold storage might prolong dormancy. Brown, et al. (6) found that dormancy in sorghum disappeared after 2 months storage at 104° F. A lower temperature in the present study and for a shorter period of time appeared to overcome dormancy.

The interaction of varieties and cold-warm storage conditions was barely significant at the five percent level of probability (Table I). The average germination percentage of seeds in warm storage of each variety was higher than in cold storage (see Table IV). These data are presented graphically in Figure 2 where the interaction is not evident. However, there was a larger difference between cold and warm storage

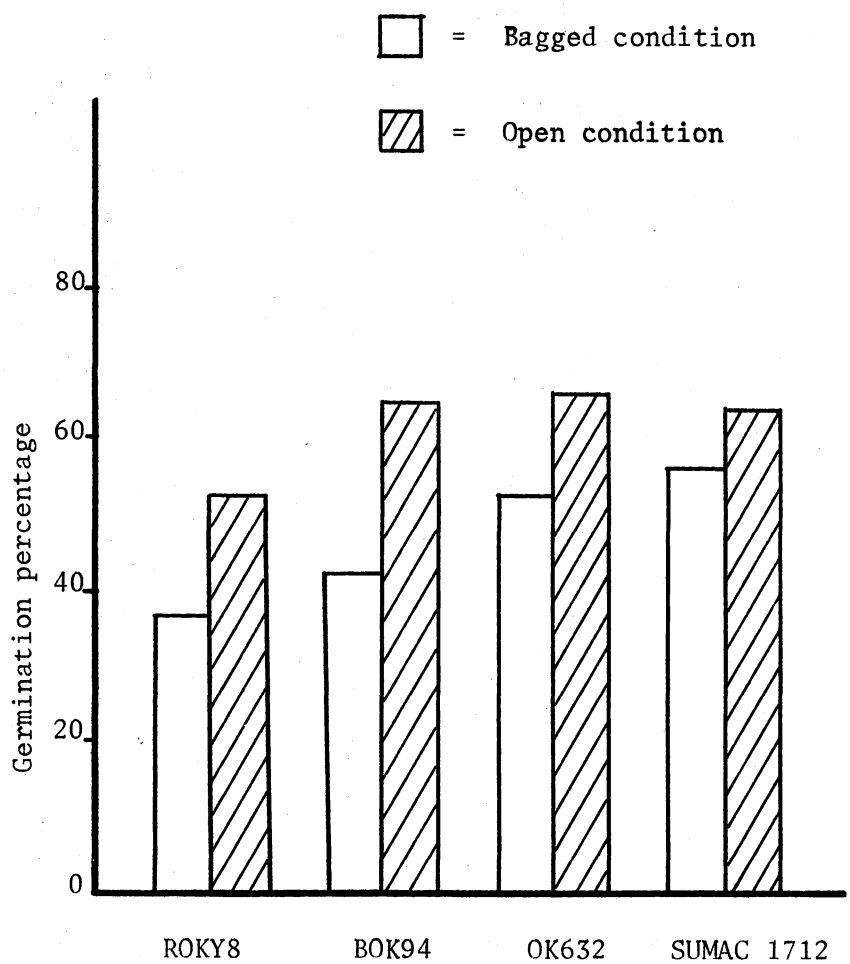

Figure 1. **Germination Percentages of Seeds from Bagged-Open Heads from Four Varieties.**

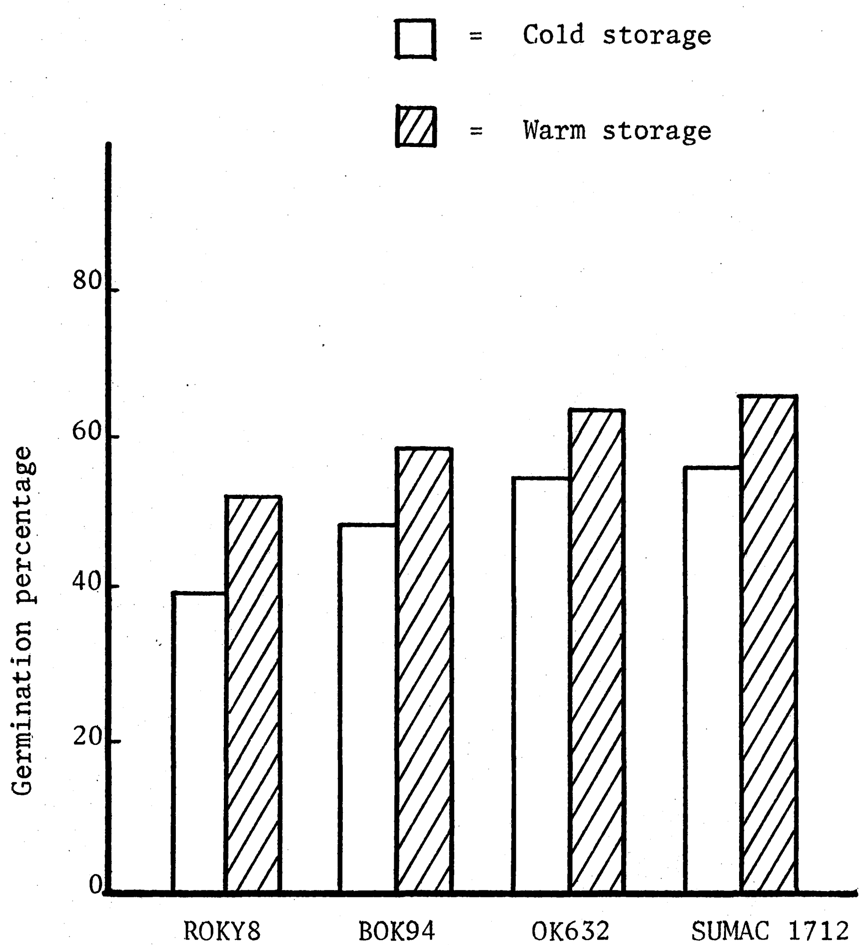

Figure 2. Germination Percentages of Seeds from Four Varieties in Cold and Warm Storage Conditions.

TABLE IV

AVERAGE GERMINATION PERCENTAGE OF SEEDS FROM COLD AND WARM STORAGE FROM FOUR VARIETIES

Variety	Storage condition	Germination percentage	Difference
ROKY8	Cold	39.4	13.0
	Warm	52.4	
BOK94	Cold	48.7	9.9
	Warm	58.6	
OK632	Cold	54.6	9.2
	Warm	63.8	
SUMAC 1712	Cold	56.0	9.2
	Warm	65.2	
Average	Cold	49.7	10.3
	Warm	60.0	

from ROKY8 than from the other varieties (Table IV).

The interaction of bagged-open heads and cold-warm storage condition was scarcely significant at the five percent level, as shown in Table I. The average germination percentages of seeds from open heads in cold and warm storage were 57.4 and 66.6, respectively, as shown in Figure 3. The average germination percentages of seeds from bagged heads in cold and warm storage were 42.1 and 53.5, respectively. Seeds from open heads germinated better than seeds from bagged heads in either storage condition. Also seeds in warm storage germinated better than seeds in cold storage. Storage condition affected the germination of seeds from both bagged and open heads in a similar way,

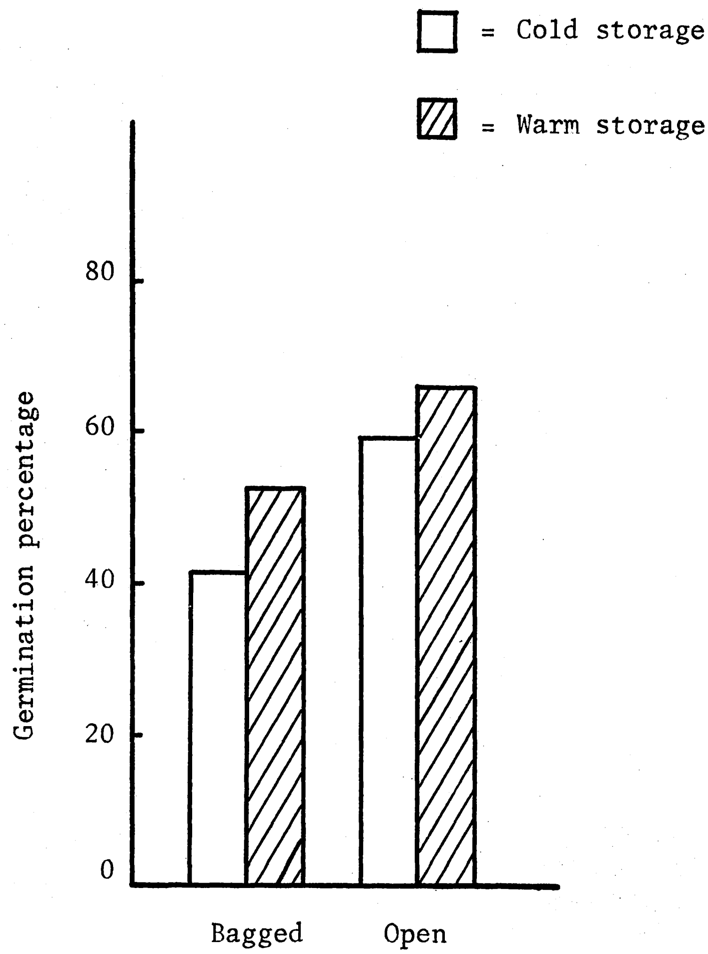

Figure 3. Germination Percentages of Seeds from Bagged and Open Heads in Cold and Warm Storage Conditions.

and the interaction is not evident in these means.

The interaction of varieties, bagged-open, and cold-warm storage condition was barely significant at the five percent level of probability as shown in Table I. Table V shows the average germinations for this interaction, along with differences between averages for each variety. It was apparent that the magnitude of these differences varied from variety to variety. The difference between warm and cold storage of bagged heads was greater than the difference between warm and cold storage of open heads for BOK94 (13.6 vs 6.3) and for Sumac 1712, (11.4 vs 6.9) but these differences were reversed for OK632, (8.3 vs 10.1) and ROKY8, (12.5 vs 13.5). This indicated that for BOK94 and Sumac 1712 cold storage of open heads reduced germination less than did cold storage of bagged heads, while the reverse was true for OK632 and ROKY8. The difference between cold-open and cold-bagged was greater than the difference between warm-open and warm-bagged for BOK94, (25.6 vs 18.3) and for Sumac 1712, (10.1 vs 5.6) but these differences were reversed for OK632, (11.4 vs 14.2) and ROKY8, (13.1 vs 14.1). This indicated that for BOK94 and Sumac 1712 bagging reduced germination of seed in warm storage less than bagging reduced germination of seed in cold storage. The pattern of germination percentage for this interaction has been plotted in Figure 4. The germination percentage of open heads of Sumac 1712 in cold storage was slightly lower than for bagged heads in warm storage, while it was the opposite for the other varieties. Although this appeared to be a slight reversal from the trend of the other three varieties, it probably contributed to the significant interaction which indicated that not all varieties reacted the same to the combination of

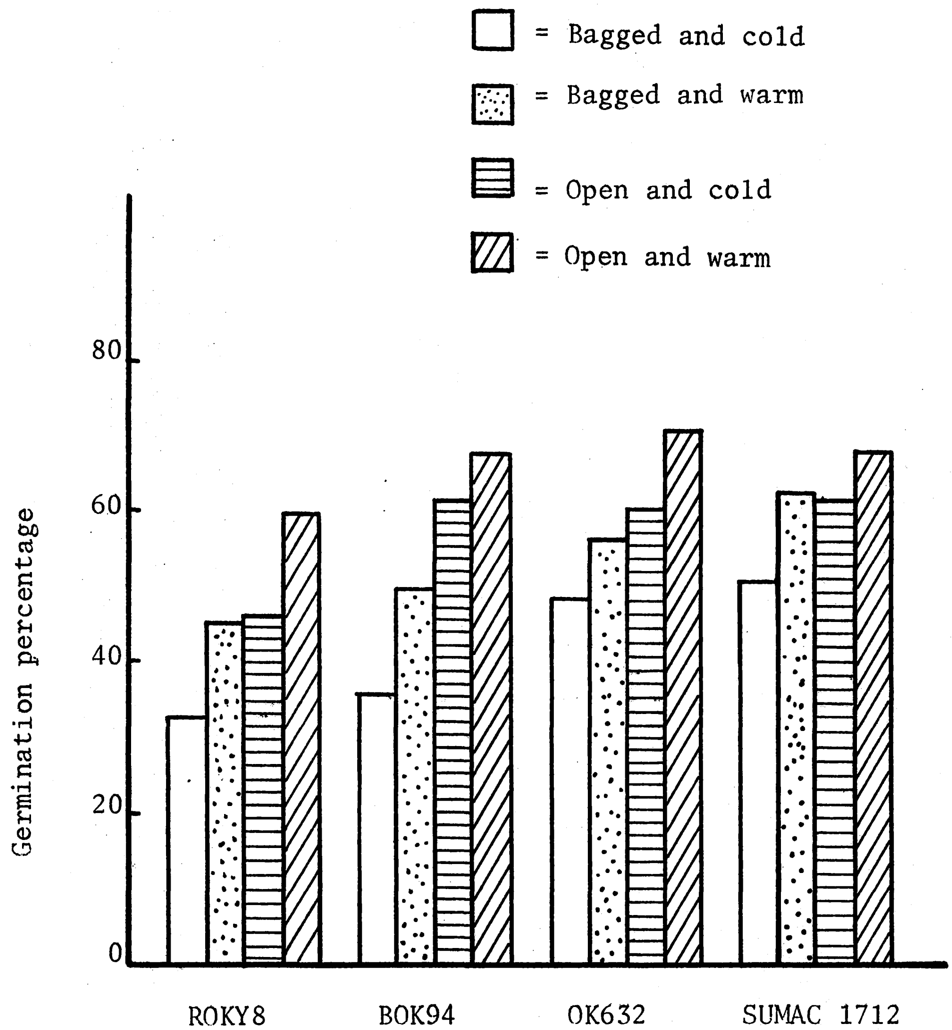

Figure 4. Germination Percentages of Seeds of Four Varieties from Bagged and Open Heads in Cold and Warm Storage Condition.

TABLE V

AVERAGE GERMINATION PERCENTAGE OF BAGGED AND OPEN HEADS IN COLD AND WARM STORAGE FOR FOUR VARIETIES

Variety	Bagged or open	Storage	Germination percentage	Difference W-C	Difference C-C	Difference W-W
ROKY8	Bagged	Cold	32.9	12.5	13.1	
		Warm	45.4			14.1
	Open	Cold	46.0	13.5		
		Warm	59.5			
BOK94	Bagged	Cold	35.9	13.6	25.6	
		Warm	49.5			18.3
	Open	Cold	61.5	6.3		
		Warm	67.8			
OK632	Bagged	Cold	48.4	8.3	11.4	
		Warm	56.7			14.2
	Open	Cold	60.8	10.1		
		Warm	70.9			
SUMAC 1712	Bagged	Cold	51.0	11.4	10.1	
		Warm	62.4			5.6
	Open	Cold	61.1	6.9		
		Warm	68.0			
Average	Bagged	Cold	42.1	11.4	15.3	
		Warm	53.5			1.31
	Open	Cold	57.4	9.2		
		Warm	66.6			

treatments.

The differences in germination percentages among collection weeks were highly significant as shown in Table I. The average germination percentage increased with the collection weeks through the fifth week (Table VI). The average germination percentage decreased slightly in the sixth week. In other words, the average germination percentage

TABLE VI

AVERAGE GERMINATION PERCENTAGE OF SEEDS
FROM SIX OF COLLECTION WEEKS

Collection week	Week after anthesis	Germination percentage
1	3	37.3
2	4	44.0
3	5	55.3
4	6	59.7
5	7	67.8
6	8	65.1

increased with the maturity of the seed. The highest average germination percentage was 67.8 in the fifth week, while the lowest average germination was 37.3 from the first week of collection. Maximum germination was reached in the fifth collection which would be 7 weeks after anthesis.

The interaction of varieties and collection weeks was highly significant, as shown in Table I, and indicates that the pattern of average germination percentage for each variety by collection week was different. The highest germination percentage for each variety occurred in a different collection week, as shown in Figure 5. The highest germination percentage for BOK94 was in the fourth collection week, while for ROKY8 it was in the fifth week, and for OK632 it was in the sixth week. Sumac 1712 had nearly the same germination from the

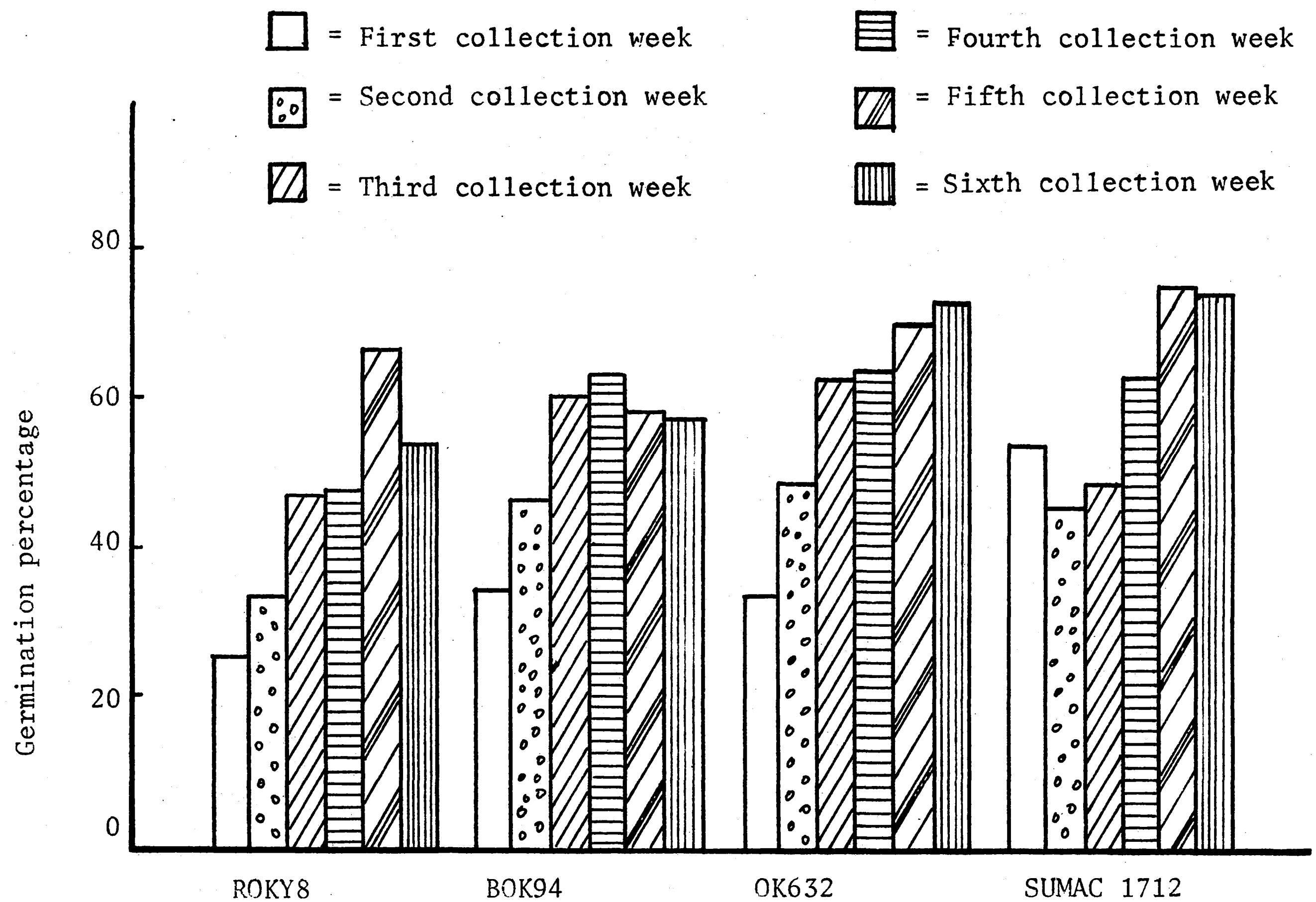

Figure 5. Germination Percentages of Seeds of Four Varieites from Six Collection Weeks.

fifth and sixth weeks. The rate of seed development of each variety was apparently not the same. For Sumac 1712, however, there was a drop in germination for the second and third weeks compared to the first collection week, indicating the possibility of the effect of dormancy.

The interaction of bagged-open heads and collection weeks was highly significant (see Table I). The average germination percentages of bagged and open heads mostly increased with the collection week through the fifth week of collection (see Figure 6), but they dropped slightly in the sixth week of collection. Experimental error might explain the slight drop in germination for the second week of bagged heads, or it could be the effect of dormancy. The seeds from open heads germinated better than seeds from bagged heads when they were compared in each collection week.

The interaction of varieties, bagged-open heads, and collection weeks was highly significant for germination percentage, as shown in Table I. Graphic forms of the data are presented in Figures 7 and 8. Generally, the average germination percentage for bagged and open heads of each variety increased with the number of the collection week. An exception was the bagged head condition for ROKY8 which dropped in the fourth week (Figure 7) almost to the level of the first and second week. Also, Sumac 1712 departed from the general pattern when germination for the first collection week was high and germination for the second and third week dropped nearly 10 percent. Either the first germination was usually high, or, more likely, the second and third germinations were lower because of the onset of dormancy. In the open condition (Figure 8) there was no drop in germination of ROKY8 in the

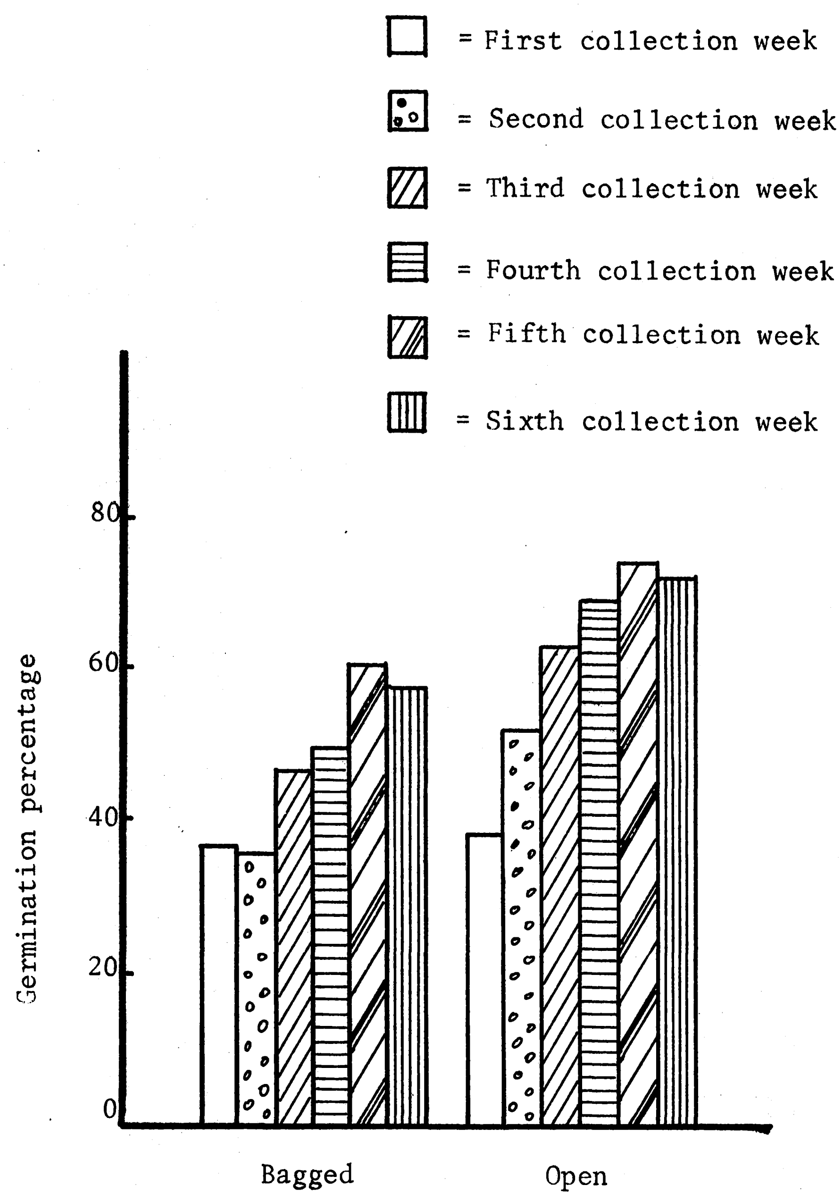

Figure 6. Germination Percentages of Seeds from Bagged and Open Heads for Six Collection Weeks.

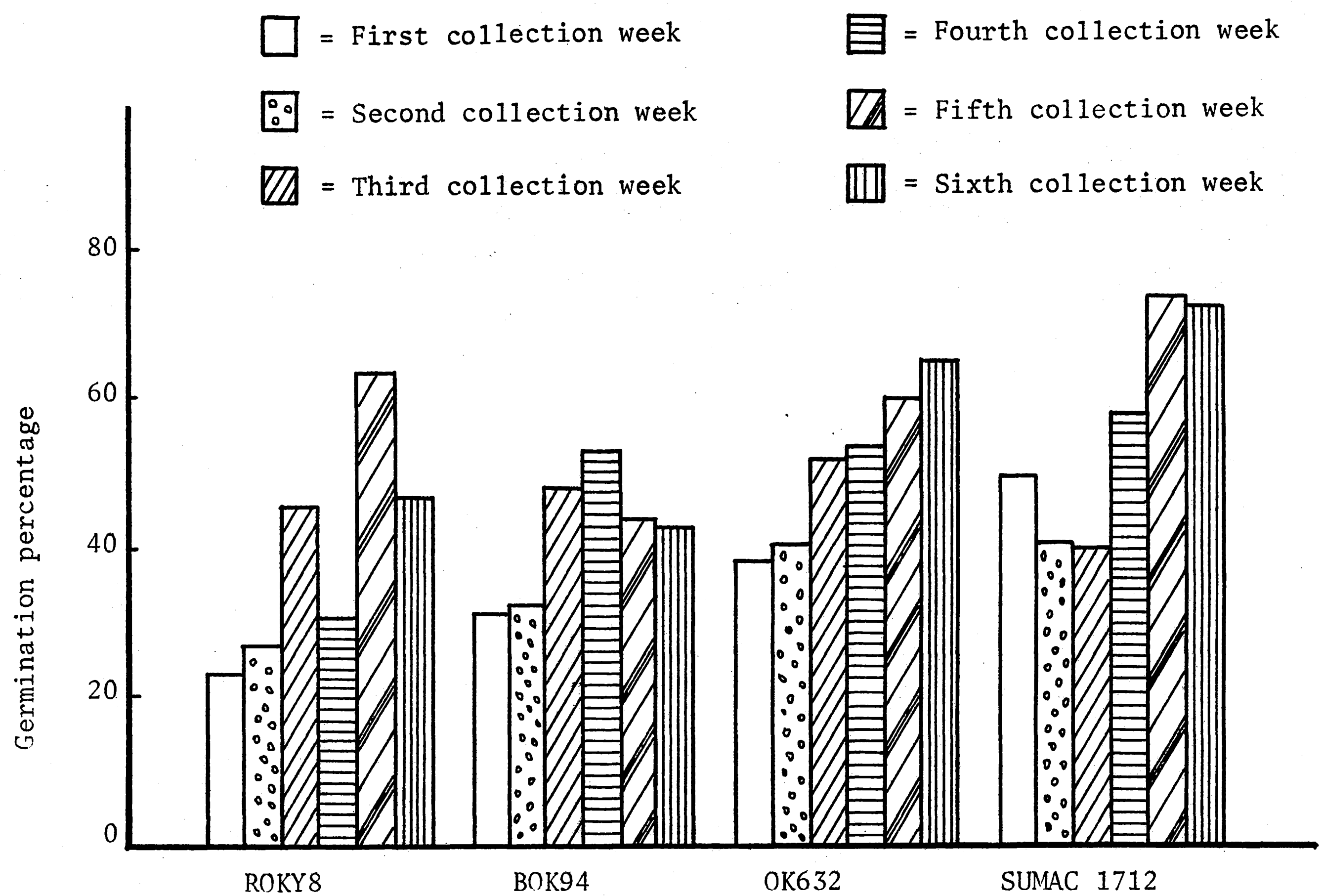

Figure 7. Germination Percentages of Seeds from Bagged Heads of Four Varieties for Six Collection Weeks.

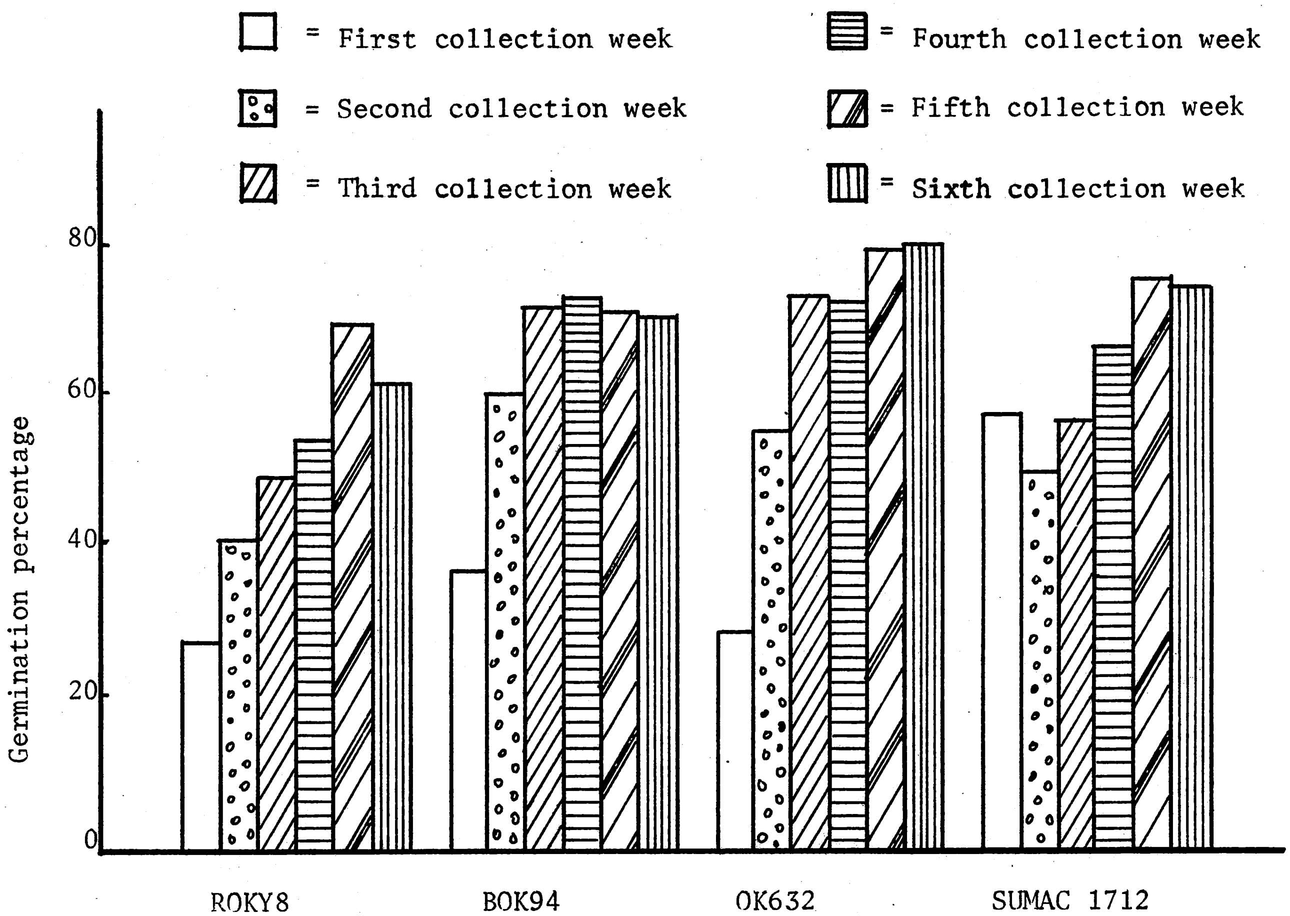

Figure 8. Germination Percentages of Seeds from Open Heads of Four Varieties for Six Collection Weeks.

fourth collection week, and there was less evidence of dormancy in Sumac 1712 in the third week. The irregular responses of the varieties to the condition imposed resulted in the significant interaction.

The interaction of cold or warm storage condition and collection week resulted in a highly significant difference as shown in Table I. The average germination percentages for both cold and warm storage increased with the collection weeks through the first five weeks as shown in Figure 9. In other words, these overall averages showed that the germination percentages increased with seed maturity in both cold and warm storage conditions, until the seeds reached maximum maturity in the fifth collection week. There was, however, a much lower initial germination from cold storage than from warm storage. This showed a difference in germination response from collection weeks to the storage condition. Warm storage conditions were more conducive to good germination.

The interaction of varieties, cold-warm storage conditions, and collection weeks was highly significant, as shown in Table I. The average germination percentage of cold and warm storage of all varieties increased generally with the number of collection weeks until seeds probably reached maturity, as shown in Figures 10 and 11. After reaching maturity, the average germination percentage dropped some except for OK632 and Sumac 1712 in warm storage and for OK632 in cold storage. There was a drop in germination in warm storage for the fourth collection week of ROKY8 and for the second week of Sumac 1712 suggestive of some dormancy. Low germination from the first and second collection weeks for three of the varieties from the cold storage condition probably caused the significant interaction. The

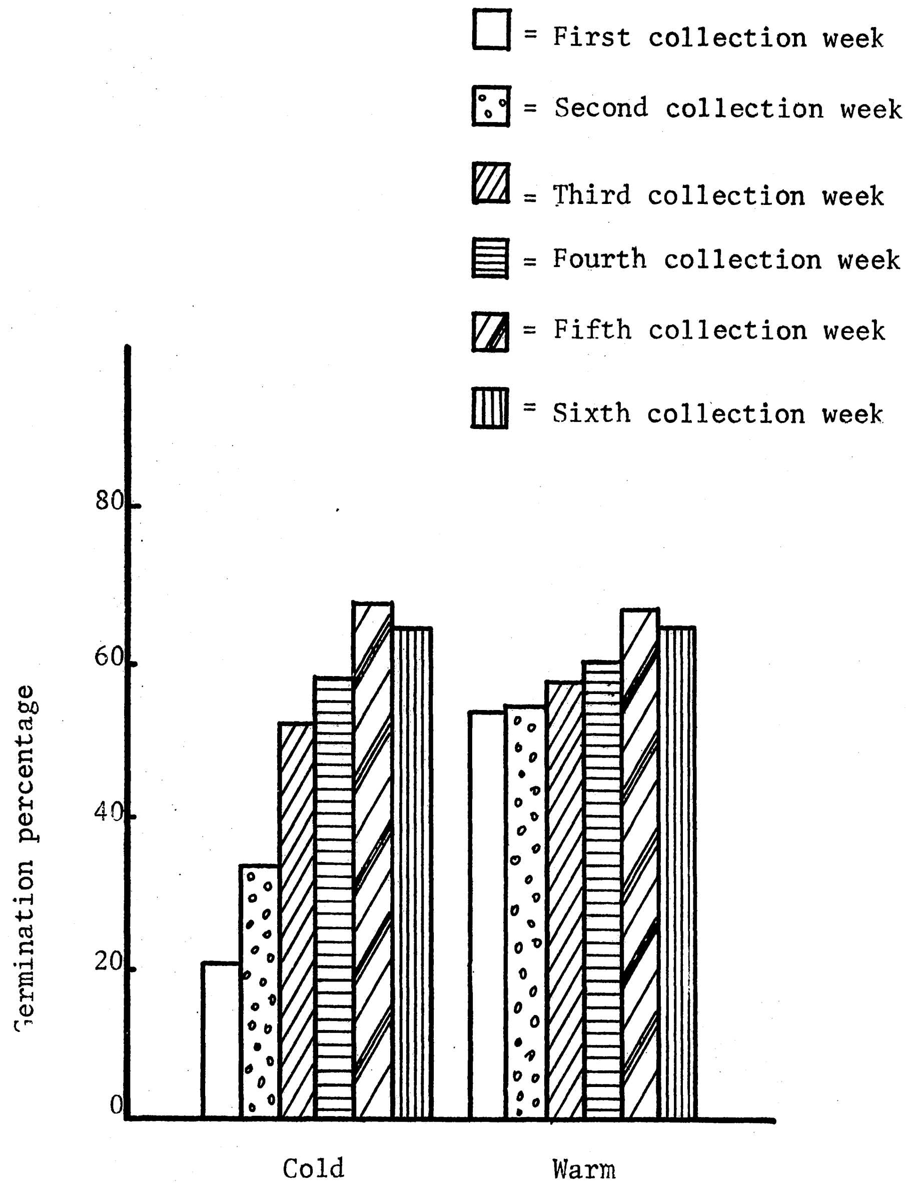

Figure 9. Germination Percentages of Seeds from Cold and Warm Storage Conditions for Six Collection Weeks.

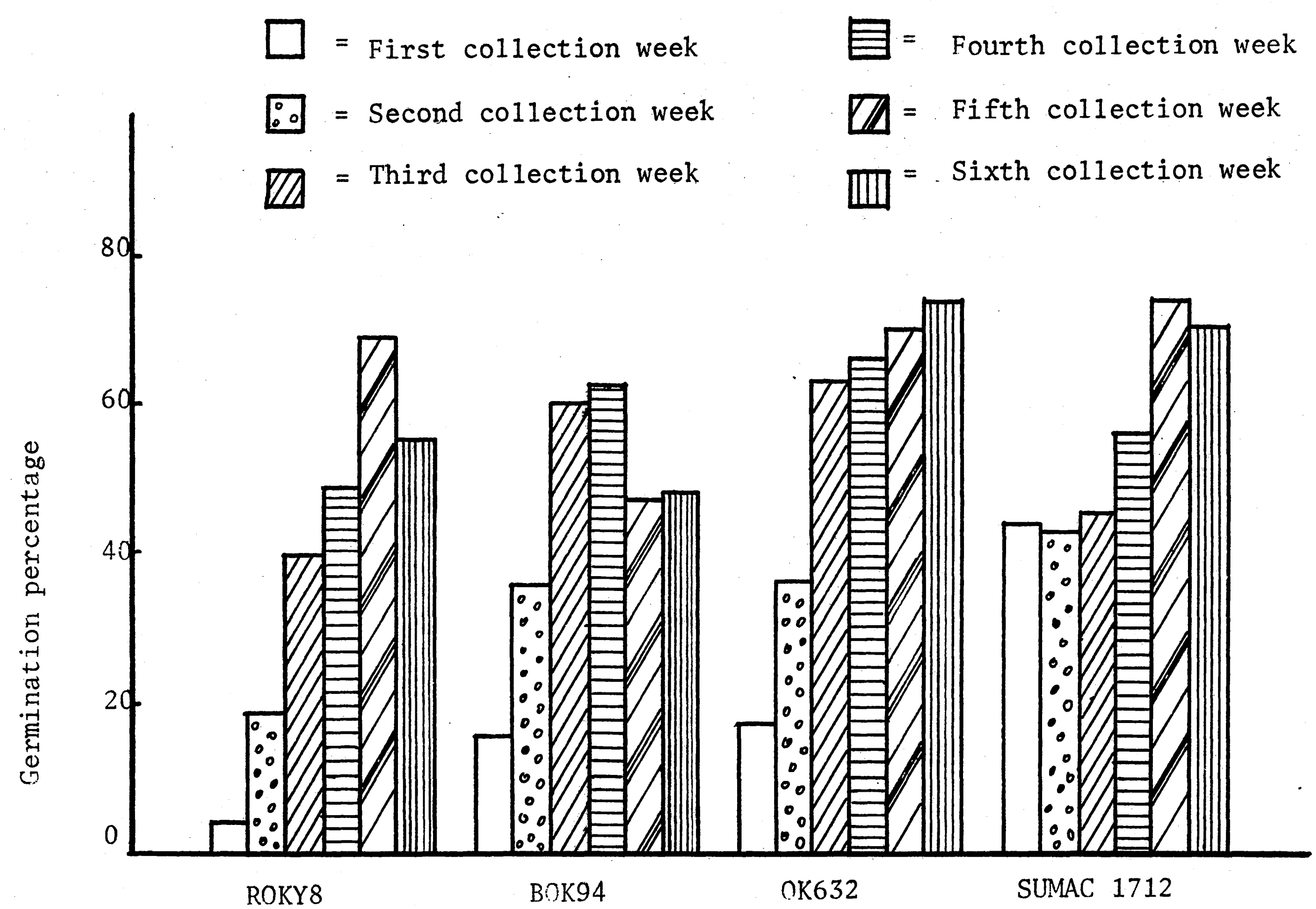

Figure 10. Germination Percentages of Seeds of Four Varieties for Six Collection Weeks from the Cold Storage Condition.

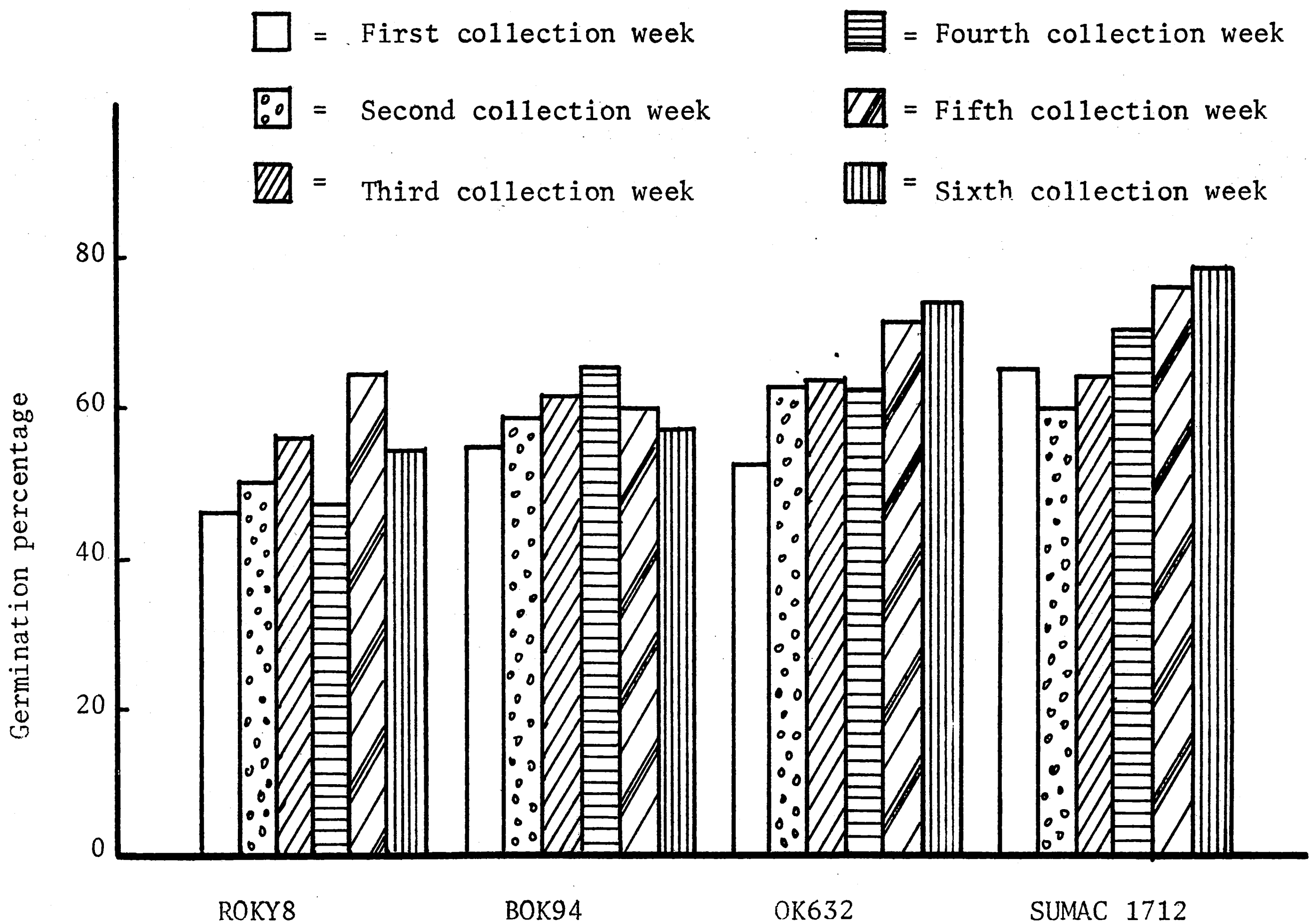

Figure 11. Germination Percentages of Seeds of Four Varieties for Six Collection Weeks from the Warm Storage Condition.

trend for three varieties was similar but Sumac 1712 showed better germination from the early collection weeks in cold storage.

There was a small though highly significant difference among germination percentages for storage weeks (see Table I). The germination percentage of the first through the seventh week of storage ranged from 52.6 to 57.1, as shown in Table VII. The highest and lowest average germination came from the first and the third week of storage, respectively. Although there was a statistically significant difference among overall germination percentages from the seven weeks of storage, the range of means was narrow and indicated that weeks of storage did not greatly affect germination. Data for zero storage week were not included in the analysis, but they were included here for comparison. They were somewhat higher than other means probably because they did not involve cold storage.

The interaction of varieties and storage weeks was barely significant at the five percent level, as shown in Table I. The pattern of the average germination percentages for storage weeks of all the varieties was similar (see Figure 12). They all started out high and declined slightly through the storage weeks. For these overall averages, length of storage did not seem to influence germination to any great extent. Possibly Sumac 1712 differed from the rest during the second and third week of storage, suggesting the possibility of dormancy.

There was a highly significant difference for the interaction of cold-warm storage conditions and storage weeks (see Table I). The average germination percentage for storage weeks in warm storage (see Figure 13) dropped in the first week of storage and then was rather

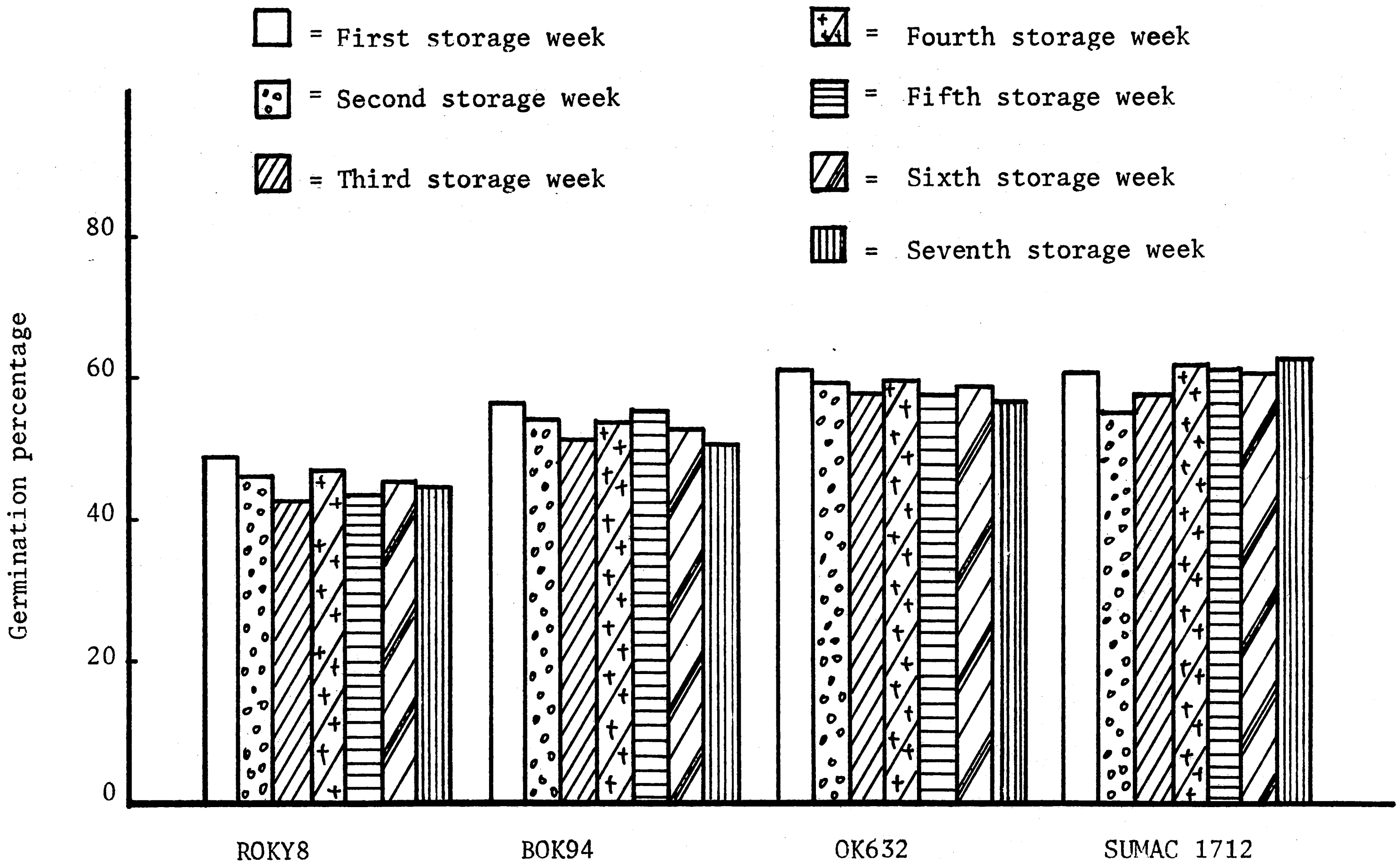

Figure 12. Germination Percentages of Seeds of Four Varieites from Seven Storage Weeks.

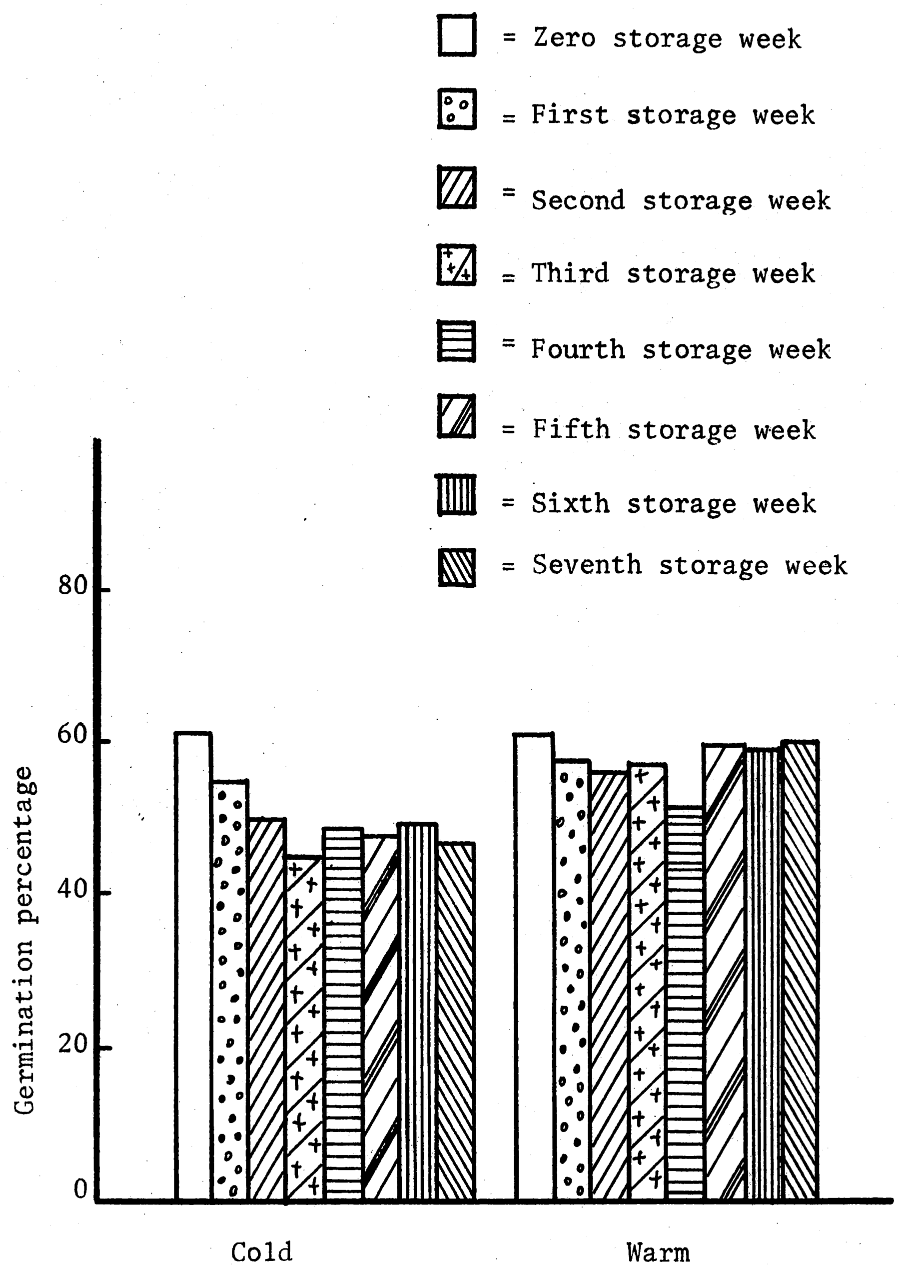

Figure 13. Germination Percentages of Seeds in Cold and Warm Storage Conditions for Seven Storage Weeks.

TABLE VII

AVERAGE GERMINATION PERCENTAGE OF SEEDS
FOR SEVEN STORAGE WEEKS

Storage week	Germination percentage
0	62.2
1	57.1
2	54.1
3	52.6
4	55.9
5	54.9
6	55.1
7	54.2

constant except for a drop in the fourth week of storage. However, the average germination percentages of seeds for storage weeks in cold storage decreased in the second and third weeks of storage. They then increased a few percentage points and remained rather constant. This indicated that cold storage depressed germination.

The interaction of collection weeks and storage weeks was highly significant, as shown in Table I. Data for zero storage week were included in Figure 14 through 20 for points of reference. These data were not part of the statistical analysis. The highest average germination percentages of seeds for the first and second weeks of collection was from the first week of storage (see Figure 14).

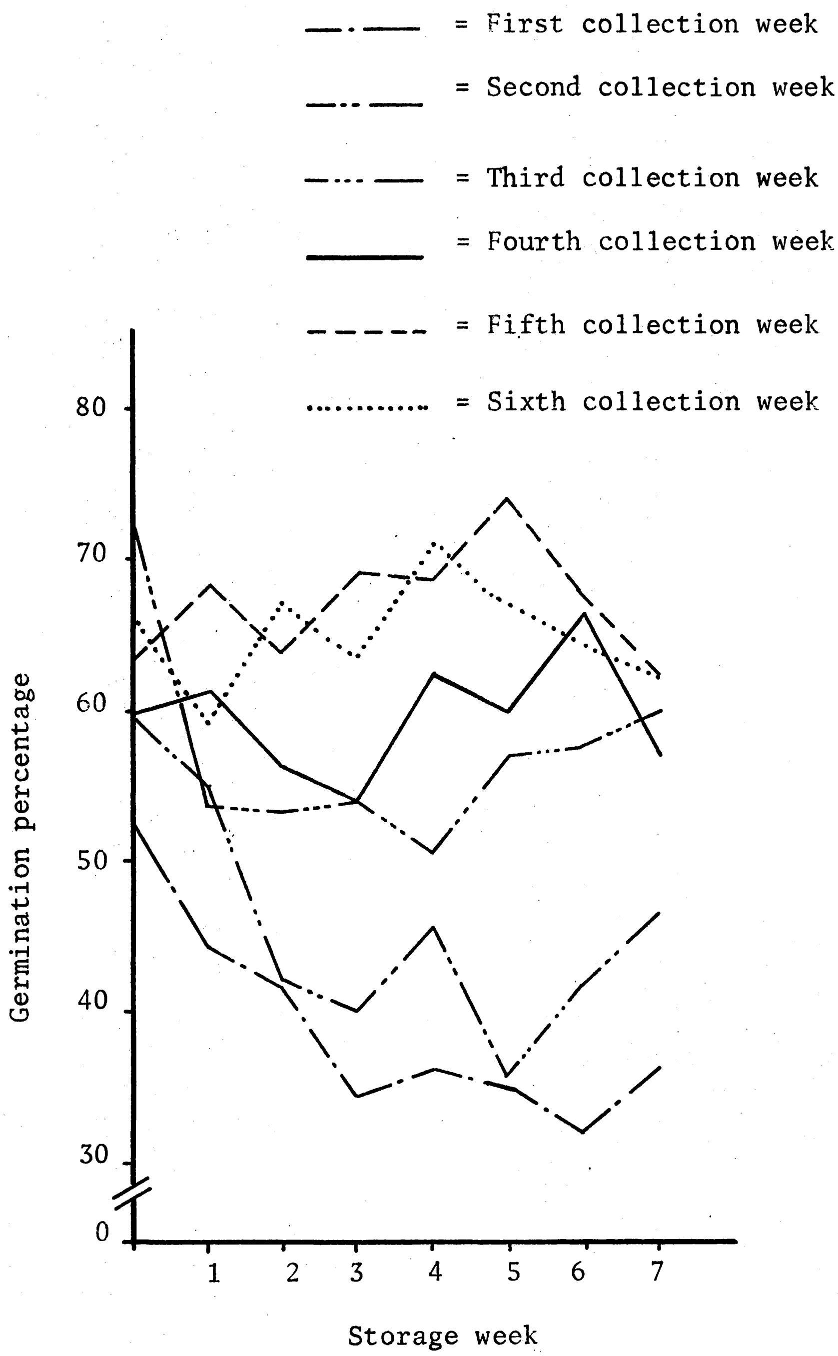

Figure 14. Germination Percentages of Seeds from Seven Storage Weeks and Six Collection Weeks.

Germination generally declined and became variable in succeeding weeks. The average germination percentage of the third, fourth, fifth and sixth weeks of collection was the highest in the zero, sixth, fifth, and fourth week of storage, respectively, and declined after that. This indicated that the more mature collections required fewer storage weeks to reach maximum germination. In other words, the more mature seeds needed less time in storage to overcome dormancy. The average germination percentage of the first and second week of collection did not support this theory perhaps because the experiment did not continue for enough storage weeks.

There was a highly significant interaction of varieties, collection weeks, and storage weeks, as shown in Table I. The highest average germination percentage of seeds for the first and second collection week of BOK94 was in the first storage week with a general decline for succeeding weeks, as shown in Figure 15. The highest average germination percentages of seeds for the third, fourth, fifth, and sixth weeks of collection were in the seventh, sixth, fifth, and fifth week of storage, respectively, and declined after that. It appeared that for the variety BOK94 the late collection weeks reached their maximum germinations with less storage weeks, whether due to normal maturation or loss of dormancy. Collection weeks one through six began to recover germination in storage weeks seven through two after reaching their minima, indicating that the more mature seeds declined in germination for a shorter period of storage. The sharp decline of the mature seeds from storage weeks six and seven are unexplained.

The highest average germination percentage of seeds for the first,

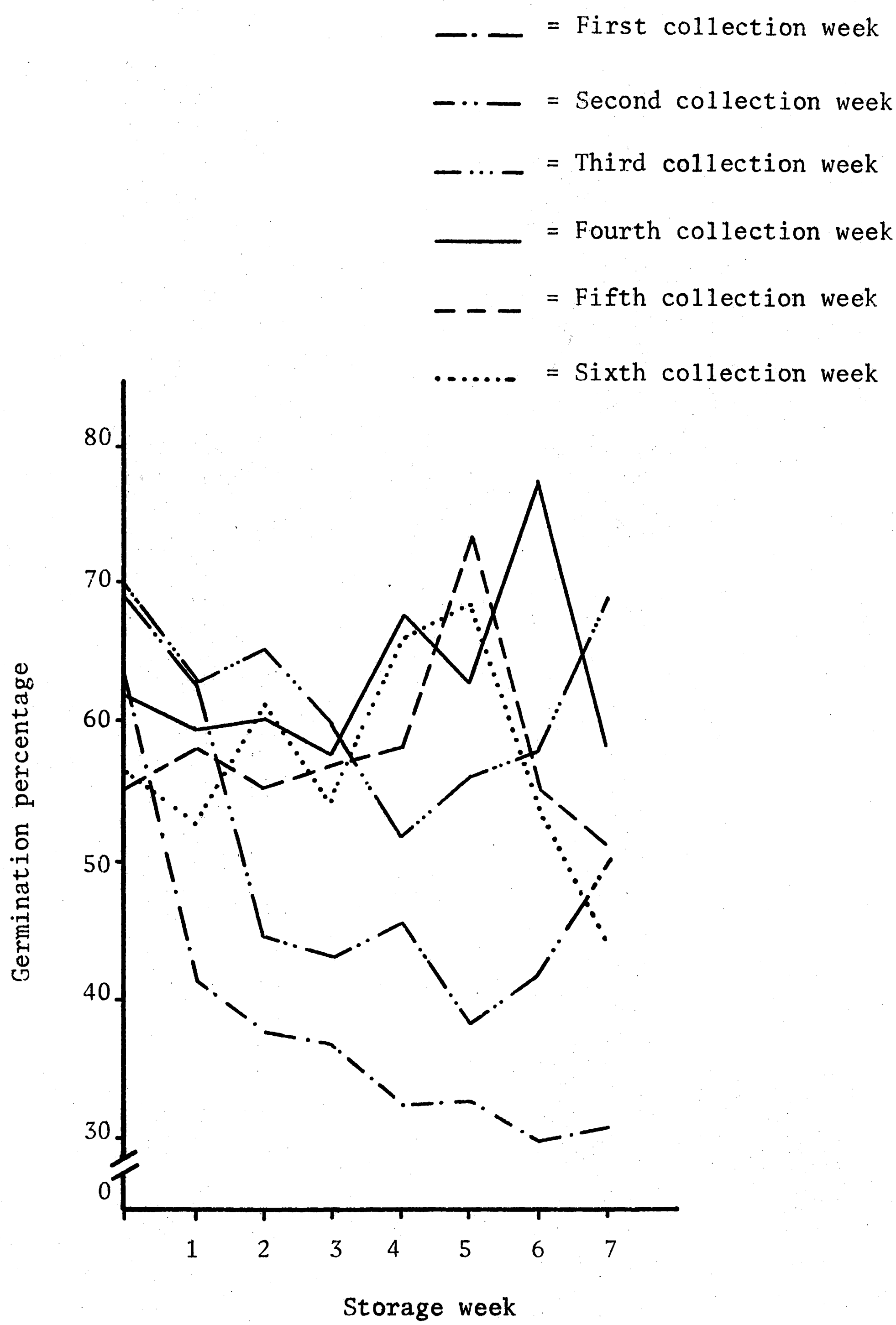

Figure 15. Germination Percentages of Seeds of BOK94 from Seven Storage Weeks and Six Collection Weeks.

second, and third week of collection of ROKY8 was from the first, zero, and zero week of storage (Figure 16). The germination generally declined for several storage weeks before improving again. Collection weeks one, two, three, and four began to recover germination in the seventh, sixth, fifth, and fourth storage week, respectively. Collection week five showed no initial decline in germination after going into storage. The highest average germination percentage of the fourth, fifth, and sixth week of collection of ROKY8 was in the sixth, fifth and fourth week of storage, respectively, again indicating that the more mature seeds reached their maximum germinations with less weeks of storage.

The highest average germination percentage of seeds of the first and second week of collection of OK632 was in the second and zero week of storage, respectively, as shown in Figure 17. The highest average germination percentage of seeds of the third, fourth, fifth, and sixth week of collection was in the zero, sixth, fifth, and fourth week of storage, respectively. Also, the recovery from minimum germination followed the same pattern as for the BOK94 and ROKY8.

The highest average germination percentage of seeds for the zero, first, second, third, fourth, fifth and sixth week of collection of Sumac 1712 was in the first, sixth, zero, fourth, third and seventh storage week, respectively (see Figure 18). Sumac 1712 did not follow the pattern established by the other varieties. It was indicated for the other varieties that germinations from collection weeks one and two were low and through seven weeks of storage seeds in these collections were not able to recover or throw off dormancy, if present. In the case of Sumac 1712, however, collection weeks one and two gained

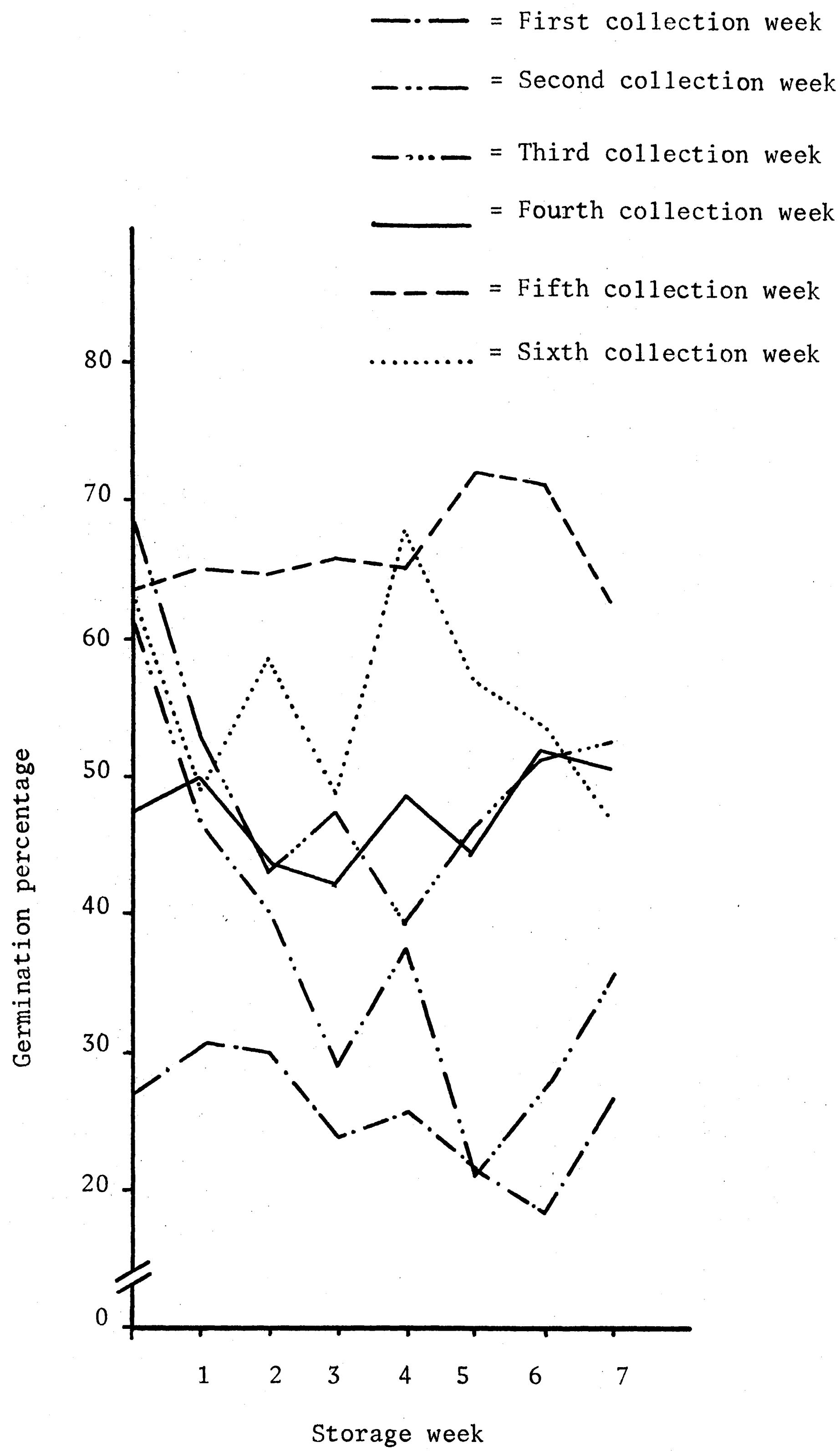

Figure 16. Germination Percentages of Seeds of ROKY8 from Seven Storage Weeks and Six Collection Weeks.

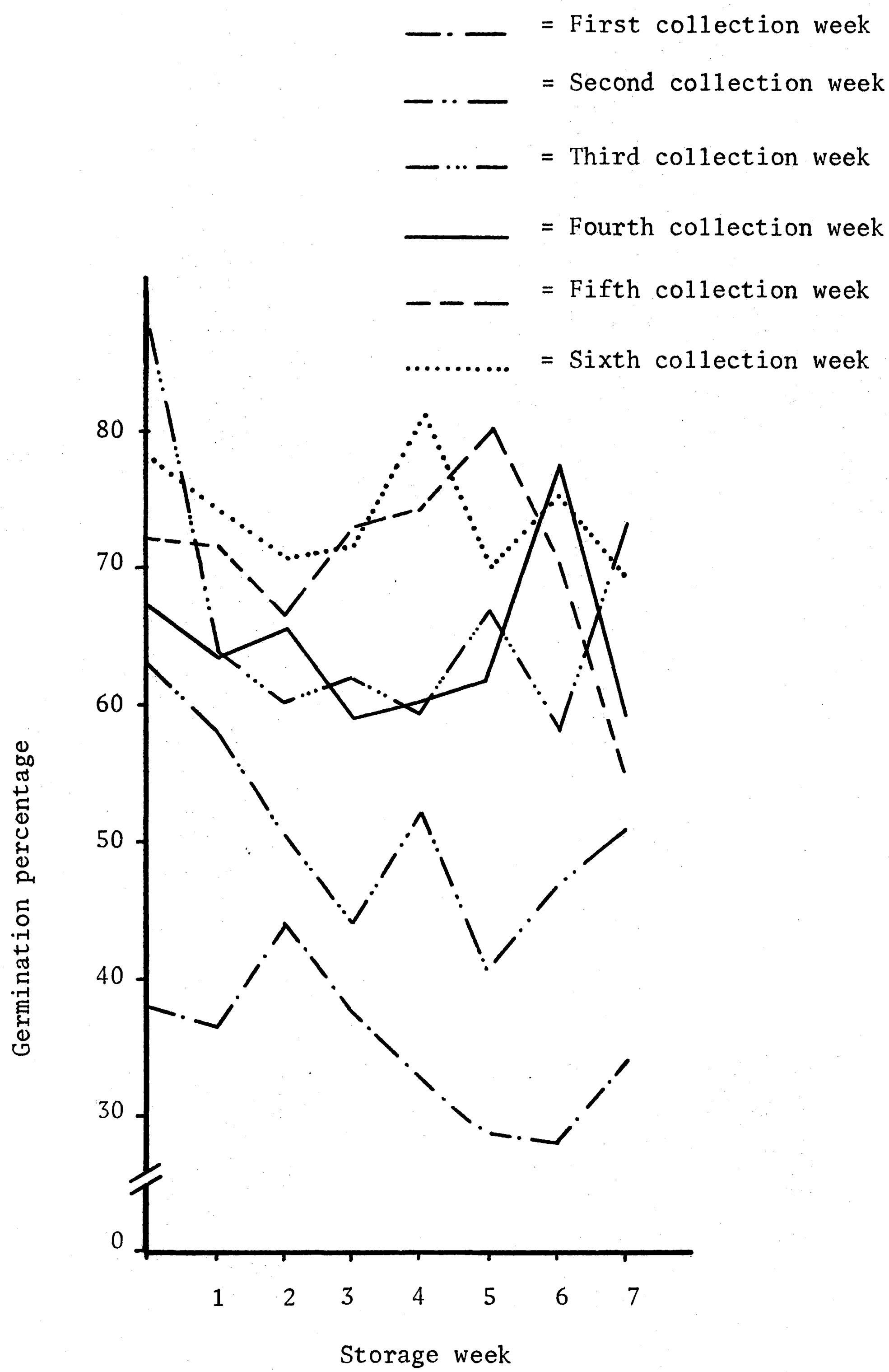

Figure 17. Germination Percentages of Seeds of OK632 from Seven Storage Weeks and Six Collection Weeks.

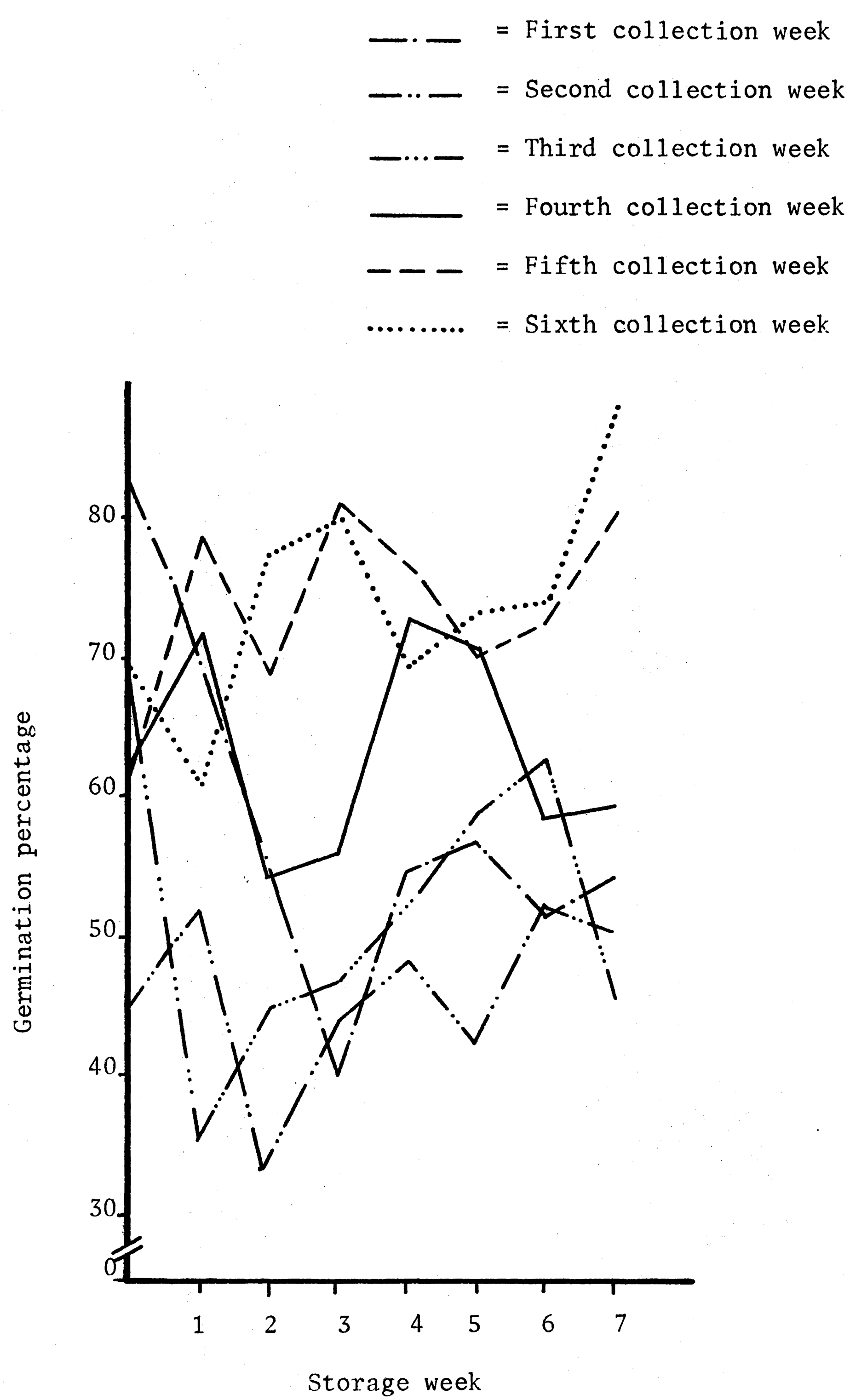

Figure 18. Germination Percentages of Seeds of Sumac 1712 from Seven Storage Weeks and Six Collection Weeks.

in germination after initial reductions. Collection week five suffered no severe change during storage, while collection week six gained substantially.

The interaction of cold-warm storage, collection weeks, and storage weeks was highly significant, as shown in Table I. The average germination percentage for collection weeks and storage weeks in the cold and warm storage varied as shown in Figures 19 and 20, respectively. The highest average germination percentage for the first and second week of collection in the cold storage was in the first week of storage, but the third, fourth, fifth and sixth week of collection had the highest average germination percentage in the sixth, sixth, fifth and fourth week of storage, respectively. The early collection weeks lost germination in storage, but the more mature collections seemed to maintain germination through the weeks of storage. The highest average germination of the first, second, third, fourth, fifth and sixth week of collection in the warm storage was in the seventh, fourth, zero, fourth, third and fourth week of storage, respectively, with no pattern evident. Generally, mature seeds would need approximately 5 weeks in cold storage and 4 weeks in warm storage to reach the maximum germination. In other words, either cold or warm storage could overcome dormancy of sorghum seed, but the warm storage could overcome dormancy faster than cold storage.

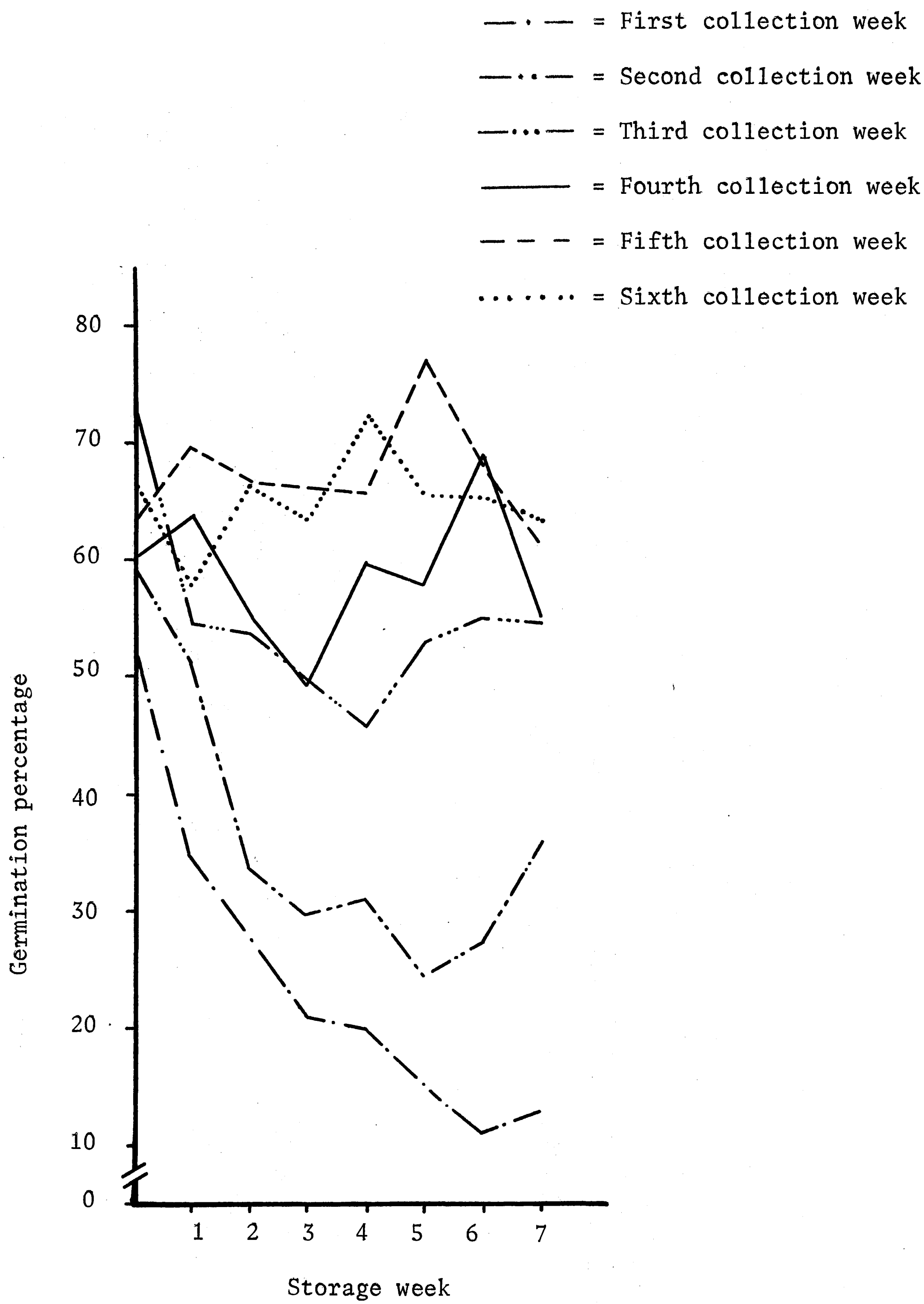

Figure 19. Germination Percentages of Seeds from Seven Storage Weeks and Six Collection Weeks from the Cold Storage Condition.

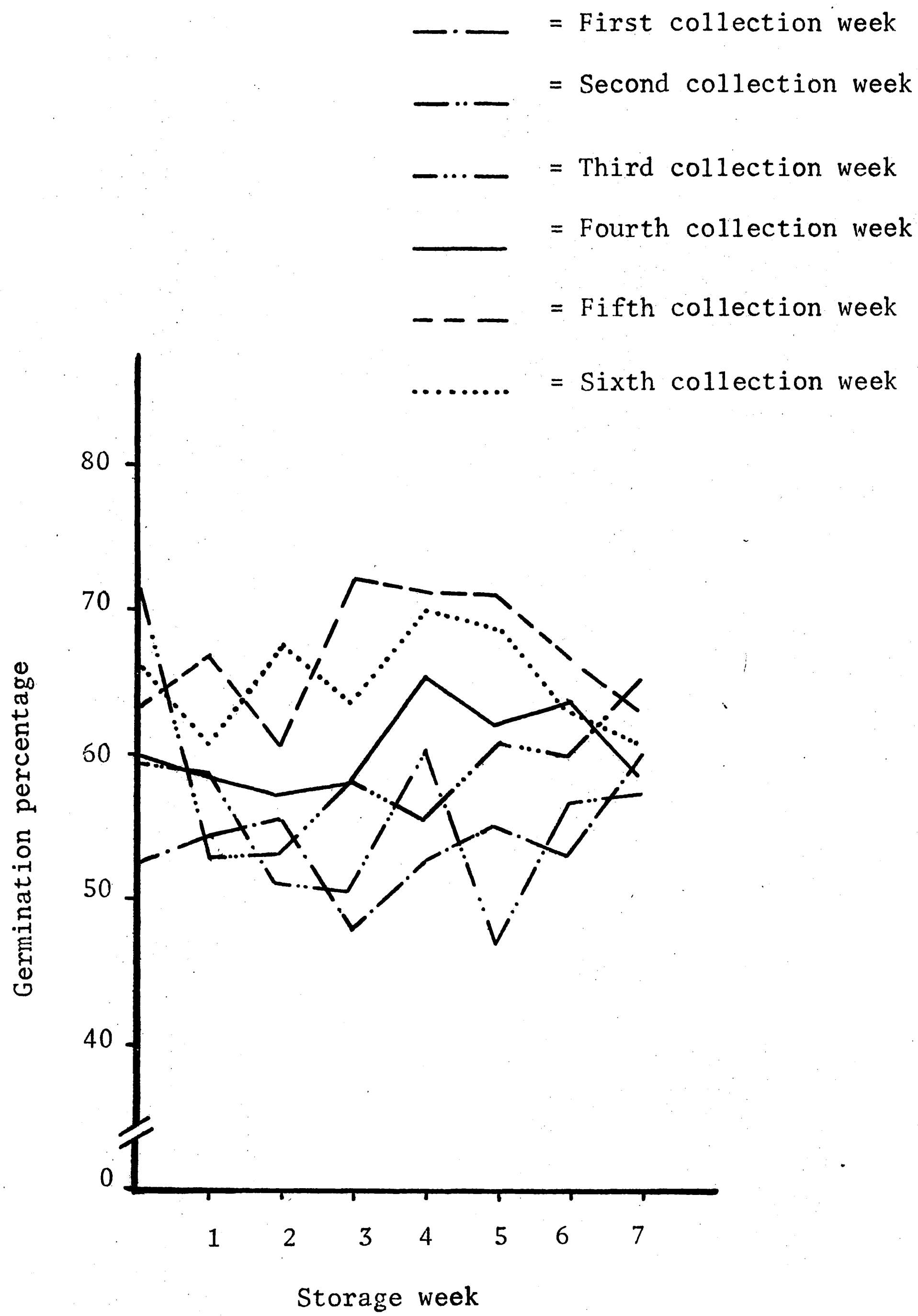

Figure 20. Germination Percentages of Seeds from Seven Storage Weeks and Six Collection Weeks from the Warm Storage Condition.

CHAPTER V

SUMMARY AND CONCLUSION

A study was conducted to determine the germination of sorghum seeds of varying degrees of maturity and to determine the age of sorghum seeds when dormancy occurs. Four sorghum varieties, OK632, BOK94, ROKY8 grain sorghum, and Sumac 1712 sorgo were planted at the Perkins Agronomy Research Station in 1972. The germinations were conducted in the laboratories of the Department of Agronomy in the same year. Seeds were germinated in 3 x 3 x 1 inch plastic germination boxes with covers in three Stults germination chambers. Seventy heads were bagged at random in each variety, just before the heads began to bloom, and 70 additional heads were marked in a similar stage of development. Ten heads each of the bagged and of the marked-open heads of each variety were harvested at 3, 4, 5, 6, 7, and 8 weeks after bagging. Samples of each were germinated immediately after threshing. Then the seed lots were divided and half of each lot was put in cold storage and the other half in warm storage. Germinations were obtained on the lots of seed after storage for 1, 2, 3, 4, 5, 6 and 7 weeks.

The average germination percentage of seeds over all conditions was highest for Sumac 1712 at 60.6 while ROKY8 had the lowest average of 45.9

The average germination percentages of seeds of open and bagged heads were 61.9 and 47.8, respectively. The average germination percentage of seeds of open heads of OK632, the highest average, was 65.8, while ROKY8 had the lowest average 52.7. The average germination percentage of seeds of bagged heads of Sumac 1712, the highest average, was 56.7 while ROKY8 had the lowest average of 39.1.

The average germination percentages of seeds of warm and cold storage were 60.0 and 49.7, respectively. The average germination percentage of seeds of ROKY8 was the lowest average in both warm and cold storage and Sumac 1712 had the highest average in both storage conditions.

Generally, the average germination percentage of seeds increased with the collection weeks or seed maturity. The average germination percentage of seeds of the fifth week of collection, the highest average, was 67.8 and the lowest average (37.3) was the first week of collection.

The range of the average germination percentage of seeds for storage weeks regardless of varieties and other conditions was 52.6 to 62.2. The highest average (57.1) and the lowest average (52.6) came from the zero and the third week of storage, respectively.

The data indicated that germination of sorghum seeds was affected by varieties, seed maturity, and storage conditions. It appeared that cold storage could induce dormancy. Sumac 1712 seemed to be the only variety among the four varieties that showed dormancy when the percent germination dropped in the second collection week in several comparisons, when the seeds were approximately 28 days old.

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